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Performance evaluation of a solar still in the Eastern Province of Saudi Arabia—an improved analysis

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ABSTRACT

The performance of a solar still is predicted though an improved and updated mathematical model. The model is based on classical energy balance equations; however, variable properties were considered in addition to a more reliable correlation for convection heat transfer from the seawater surface and the still glass cover. The effect of density variation within the solar still due to water vapor concentration difference is taken into consideration through a modified expression of the temperature difference ($\Delta T'$) and a more reliable expression for the heat transfer coefficient within the still that was developed for tilted covers. The performance of the still is validated against the published experimental values. In addition, the (distillate) productivity was reported for two days that represent both summer and winter conditions in Dhahran, Saudi Arabia. A parametric study was performed to identify the effect of the most influential parameters on the still performance. In addition, a sensitivity analysis was carried out to identify the most influential parameters on the solar still productivity.

Keywords: Solar still; Performance evaluation; Mathematical model

1. Introduction

A solar still mainly consists of an air tight basin, usually constructed out of concrete, galvanized iron sheet, or fiber-reinforced plastic with a top cover of transparent material like glass or plastic. The inner surface of the base known as the basin liner is blackened to have high solar absorptivity. Solar irradiation passes through the glazing cover and is absorbed by the blackened basin. As water is heated, the vapor is driven out from the water surface. The resultant water vapor is condensed on the inner side of the glass cover and runs down into the troughs (refer to Fig. 1), while the brackish or saline water is fed inside the basin for purification using solar energy on the other side. Stills may require flushing to prevent salt precipitation. The still acts as a heat trap because the glass is transparent to the incoming sunlight, but it is opaque to the long-wave (infrared) radiation emitted by the hot water. Typical design problems encountered with solar stills are brine depth, vapor tightness of the enclosure, distillate leakage, methods of thermal insulation, and cover slope, shape and material.

Modifications and mode of operations introduced in conventional solar stills lead to a classification of passive and active stills. In the case of active solar stills, an extra-thermal energy by external equipment is fed into the basin of passive solar still for faster evaporation.

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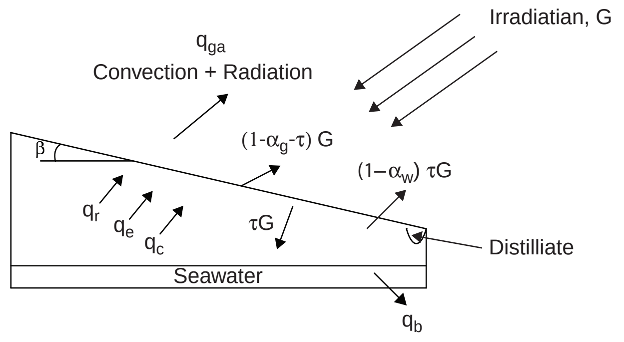

Fig. 1. Solar still geometry and energy transfer mechanisms.

The external equipment may be a collector or a concentrator panel [1], waste thermal energy from any chemical/industrial plant [2] or conventional boiler. If no such external equipment is used then that type of solar still is known as passive solar still [3]. Different types of solar stills available in the literature are conventional solar stills, single-slope solar still with passive condenser, double condensing chamber solar still [4], vertical solar still [5], conical solar still [6], inverted absorber solar still [7] and multiple effect solar still [8,9]. Other investigators have used different techniques to increase the still production. Nijmeh [10] used dissolved salts, violet dye, and charcoal to enhance performance. These techniques increase its solar absorptivity. An increase of the still productivity of about 27% was reported due to the use of violet dye.

The increased productivity from a still by lining its bed with charcoal particles was also reported by Naim and Abd El-Kawi [11]. They reported 15% increase of productivity compared to wick-type stills. The presence of charcoal leads to a capillary action by the charcoal partially immersed in a liquid and its black color as well as its surface roughness increases the evaporation rate and reduces the thermal capacity. In a follow-up study, they added energy storage units to the solar still that lead to a significant increase in productivity [12]. The idea to use two stills, one on top of the other was applied by Al-Karaghouli and Alnaser who compared the performance of single and double-basin solar stills [13,14]. Multi stage water stills were also considered with either horizontal stages with expansion nozzle and heat recovery features by Jubran et al. [15], and vertical ones by Tanaka et al. [16]. Cascaded type solar still was introduced by Satcunanathan and Hanses [17].

Tiwari developed a multiple-wick-type solar still in which blackened wet jute cloth forms the liquid surface [18]. Jute cloth pieces of increasing lengths were used, separated by thin black polyethylene sheets resting on foam insulation. Their upper edges are dipped in a saline water tank, where capillary suction provides a thin liquid sheet on the cloth, which is evaporated by solar energy. An increase in still productivity compared to conventional stills was reported. Apparently, the distance of the gap between the evaporator tray and the condensing surface (glass cover) has a considerable influence on the performance of a solar still that increases with the reduction in the gap.

Thermodynamic and economic considerations in solar stills are given by Goosen et al. [19] and by Abdel-Rehim and Lasheen [20] who proposed a solar still that includes a heat exchanger. Oil, heated by solar energy, circulates from a solar collector to a heat exchanger placed in the still in order to heat the saline water for higher productivity. Sharma and Mullick developed a semi-empirical equation to estimate glass cover temperature to calculate the upward heat flux and evaporation [21]. In another paper they developed a calculation procedure to account for the changes in the heat transfer coefficients over a complete day [22]. The factors influencing the still productivity were investigated by Cooper [23]. He indicated the upper limit of a solar still productivity both theoretically and experimentally. Mimaki et al. carried out measurements of performance parameters of both basin type and tilted wick solar stills and compared the measured values with a theoretical analysis of heat and mass transfer processes indicating the superiority of the tilted wick still [24]. Yadav and Prasad investigated analytically the transient behavior of a basin type solar still. They indicated the effect of energy storage term for the continuous distillate production [25]. Yadav and Yadav have also considered a solar still integrated with a tubular solar energy collector and performed a transient analysis for the still performance [26]. Solar still designs in which the evaporation and condensing zones are separated are described by Hussain and Rahim [27] and El-Bahi and Inan [28]. Besides, a device that uses a 'capillary film distiller' was implemented by Bouchekima et al. [29] and a solar still integrated in a greenhouse roof is reported by Chaibi [30], Radhwan and Fath [31] and Mari et al. [32]. Another class of active solar stills in which the distillation temperature is increased by flat plate collectors connected to the stills is given in references [33,34].

Recently, Phadatare and Verma showed the superiority of using glass cover for a plastic solar still in comparison with Plexiglas in terms of heat transfer coefficients as well as water evaporation and distillate productivity [35]. Khalifah and Hamood investigated experimentally the correlations that were used to show the productivity, brine depth and dye [36].

A careful study of the literature reveals that a considerable amount of theoretical and experimental work is carried out. However, almost all of the analytical formulations do not take into account the effect of property variation in the still performance, whereas the simple calculations indicate that the productivity is sensitive to these variations. Accordingly, the effect of property variation on the solar still performance is taken into account in the present analytical formulation. In addition, more reliable and updated correlations for predicting the heat transfer coefficients considering the effect of buoyancy attributable to the fact that water vapor is lighter than air within the still are used.

1.1. Mathematical formulation

Energy balance for the solar still is shown schematically in Fig. 1. Various heat transfer components are shown in this Figure including solar irradiation falling on the solar still, heat transfer within the solar still that includes the thermal radiation transmitted through the glass cover to the water surface and heat transfer by convection, radiation and evaporation form the water surface back to the glass cover, heat loss through the still opaque material and heat loss to the ambient air through both convection and radiation heat transfer modes. It is assumed that the capacitance of the glazing is small compared to that of water and basin and hence is neglected in the present work. The transient energy balance equations for the solar still as described by Duffie and Beckman [37] based on the original analysis of Dunkle [38] are summarized in this section.

Considering the thermal capacitance of seawater, the energy balance results in the following Eq. (1)

$$\alpha_w \tau G = q_{ga} + q_b + m\, c_P \frac{dT_w}{dt} \tag{1}$$

where energy losses from the water body to the glass cover and from the water body to the base of the still can be respectively, written as Eqs. (2) and (3),

$$q_{ga} = q_r + q_c + q_e \tag{2}$$

$$q_b = U_b \left(T_w - T_b\right) \tag{3}$$

Heat flux from the water to cover by radiation, q_{rad} can be estimated using the relation,

$$q_r = F_s \sigma (T_w^4 - T_g^4) \tag{4}$$

In this Eq. (4), F_s is defined as the radiation shape factor. It depends on the geometry of the still and the nature of solar radiation. The geometry can be approximated by two parallel planes. The radiation involved is considered as diffuse radiation in long wavelengths, so that specular reflection between the transparent cover and water surface is negligible. As a result, the shape factor can be closely approximated by the emissivity of the water surface, usually taken as 0.9 for the conditions inside the still. Thus, Eq. (4) can be approximated as Eq. (5)

$$q_r = 0.9\sigma (T_w^4 - T_g^4) \tag{5}$$

The heat flux from the water to cover by natural convection and evaporation can respectively, be written as Eqs. (6) and (7),

$$q_c = h_c (T_w - T_g) = h_c \Delta T \tag{6}$$

$$q_e = m_d h_{fg} \tag{7}$$

The heat loss from the transparent cover to the surrounding depends both on radiation to the sky and convection loss coefficient due to the surrounding (ambient) air. Radiation to the sky depends on the effective sky temperature, which is generally taken as 11 °C less than the ambient temperature. The convective portion is taken as a function of the wind speed. This heat transfer (losses) component can be expressed as Eq. (8)

$$q_{ga} = \varepsilon_g \sigma [T_g^4 - (T_a - 11)^4] + h_{ga}(T_g - T_a) \tag{8}$$

Eqs. (1)–(8) represent the key equations for solar still analysis. In addition, the convection correlations that describe convection from the water surface to the glass cover as well as from glass cover to the ambient are described below.

1.1.1. Natural convection within the solar still

Natural convection heat transfer coefficient within the still was originally given by Dunkle [38] that was also used by many researchers including the classic text book by Duffie and Beckman [37] and others [21,22]. This is a rather old formula. Improvements to this formula were provided by many researchers such as Tiwari [18,41,42] and Hollands et al. [39]. Tiwari conducted series of experiments and obtained an empirical formula based on experimental values. This formula was reported in the form $Nu = c\, Ra^n$; however, the formula given by Hollands accounts for tilt angles that was also used earlier by Mimaki et al. [24]. This correlation is reported to be the most reliable one for predicting natural convection coefficient between the two parallel plates [37].

This correlation is modified in the present analysis for solar still applications by replacing the temperature difference by an equivalent temperature difference; taking into account the added buoyancy attributable to the fact that water vapor is lighter than air. Therefore, the modified heat transfer coefficient can be expressed as Eq. (9)

$$Nu = \frac{h_c L}{k_{fluid}} = 1 + 1.44\left[1 - \frac{1708\left(\sin 1.8\beta\right)^{1.6}}{Ra\cos\beta}\right] \times\left[1 - \frac{1708}{Ra\cos\beta}\right]^{+} + \left[\left(\frac{Ra\cos\beta}{5830}\right)^{1/3} - 1\right]^{+} \tag{9}$$

where the meaning of the plus sign(+) in the exponentiation is that if the term is negative (< 0), it is taken = 0 (only positive values are considered).

Following the approach suggested by Dunkle, the modified temperature difference is used in the Raleigh number equation [38]. This can be written as Eq. (10)

$$\Delta T' = \left(T_w - T_g\right) \times\left[\left(\frac{P_w - P_{wg}}{P_{ambient}\left(\frac{M_{dry\,air}}{M_{dry\,air} - M_{wvapor}}\right) - P_w}\right)(T_w + 273)\right] \tag{10}$$

By analogy between heat and mass transfer, the distillate (productivity) mass flow rate can be written as Eq. (11)

$$m_D = 9.15\times 10^{-7} h_c \left(P_w - P_{wg}\right) \tag{11}$$

A comparison between the three formulae are shown in Fig. 2a [33,38,39]. The Figure shows that the classic formula given by Dunkle [38] overestimates the convection heat transfer coefficient from the water surface to lower surface of the glass cover whereas the other two formulae are in a very good agreement with each other.

1.1.2. Wind loss coefficient

There are many convection heat loss coefficient relations available in the literature, dealing with the glass cover to ambient air; however, a thorough investigation of the literature reveals the equation recommended by McAdams [43] is based on 0.5 m^2 flat plate in which the heat transfer coefficient is given by Eq. (12):

$$h = 5.7 + 3.8\,V \tag{12}$$

Another empirical formula suggested by Watmuff et al. [44] is also based on 0.5 m^2 plate surface area, he recommended that for only convection, the heat loss coefficient can be written as Eq. (13)

$$h = 2.8 + 3.0\,V \tag{13}$$

It is not reasonable to assume that the above equation is valid at other plate lengths. Therefore, the formula given by Sparrow et al. [45] and recommended by Duffie and Beckman [37] appears to be more reliable for predicting heat loss from the glass cover. It is given by Eq. (14):

$$Nu = \frac{h_{ga} l}{k_{air}} = 0.86\,\mathrm{Re}^{\frac{1}{2}}\,\mathrm{Pr}^{\frac{1}{3}} \tag{14}$$

This equation is based on experiments on rectangular plates at various orientations and found to give reliable predictions for Reynolds number range of 2×10^4 to 9×10^4, where the characteristics length l is defined as four times the plate area divided by the still perimeter. The comparison between the three equations is shown in Fig. 2b where the Figure shows thatboth McAdams and Watmuff equations overestimate the heat transfer coefficient for the current still surface dimensions.

It should be noted that the solution of the above coupled (heat and mass transfer) equations are very sensitive to various thermo-physical properties, the present solution procedure was based on variable properties (c_p, μ, α, ρ, k, h_{fg}, P_w, P_g… etc.) that are updated once any value of the temperatures is calculated. This approach is expected to provide accurate estimation of the still production parameters compared to the constant properties schemes based on average values generally reported in the literature [40–42].

1.3. Validation and comparison with experimental and theoretical results

To validate the current model, a comparison with both experimental and theoretical results published in the literature was carried out and presented in Figs. 3–5. Fig. 3a shows a comparison with the experimental work of Tiwari and Tiwari [46]. The measured values of solar radiation, air temperature and wind velocity are used to predict the water production and water temperature for a 24-hour period. It can be seen from the Figure that there is an excellent agreement between the model and measured values. This Figure also shows an improvement of the results by using the present procedure when compared to the previous models in terms of water productivity and the basin water temperature.

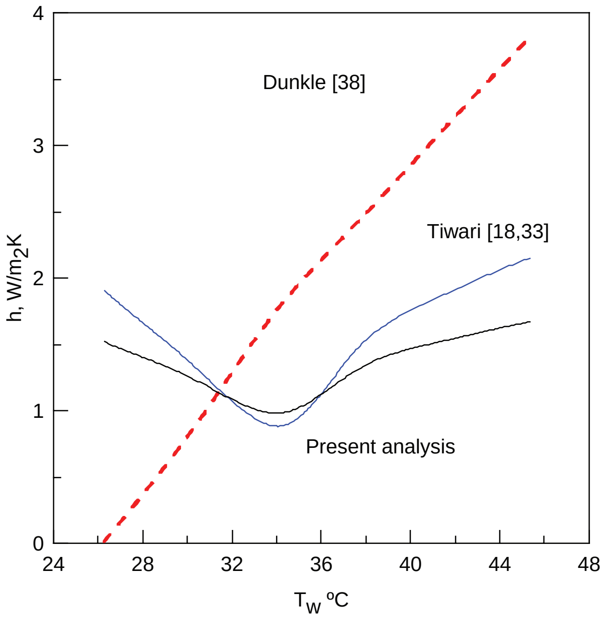

Fig. 2a. Convection heat transfer coefficient within the still.

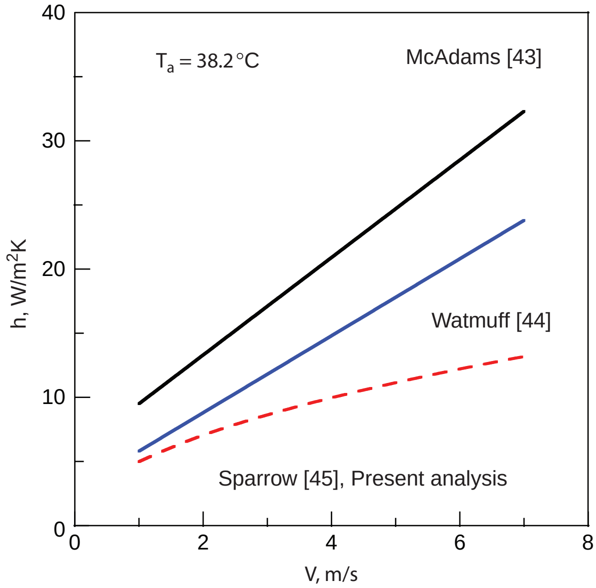

Fig. 2b. External convection heat transfer coefficient due to wind speed.

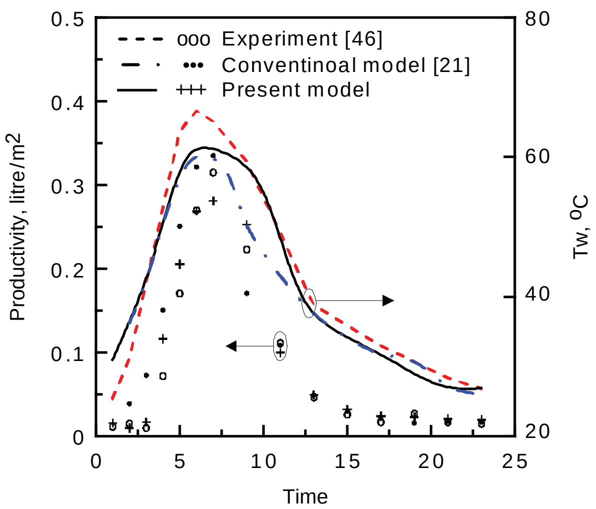

Fig. 3a. A comparison of the still hourly productivity with Tiwari and Tiwari [46].

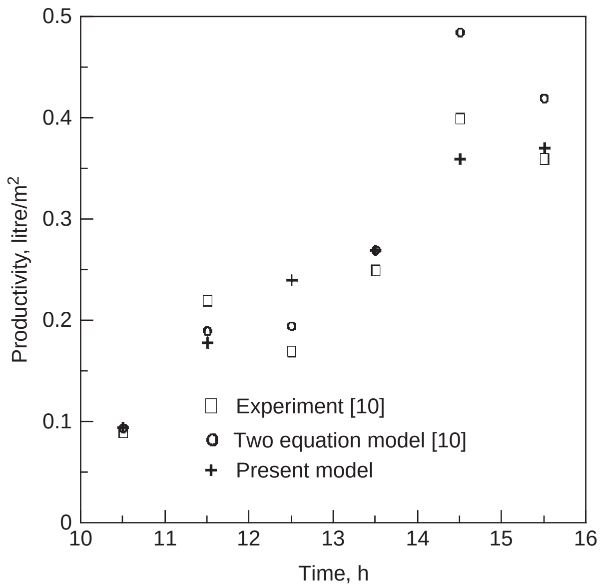

Fig. 3b. A comparison of the hourly still productivity with Nijmeh et al. [10].

Fig. 3b shows a comparison with the experimental results reported by Nijmeh et al. of a solar still in Jordan [10]. Local weather data (solar radiation intensity and ambient temperature) were used to predict the solar still production as shown in the Figure. A good agreement between the measured and calculated (integrated) values of the productivity is noticed except at 12:00 noon. In this respect, the measured value is believed to lack accuracy since both solar radiation intensity and ambient temperature are increasing, hence increasing the water temperature. This should lead to an increase in the productivity (not a decrease as shown in the Figure). It is important to mention that Nijmeh et al. measured

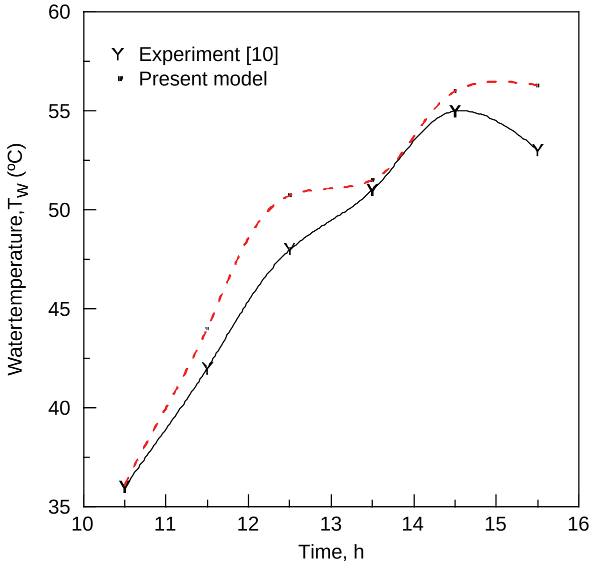

Fig. 4a. A comparison between calculated and measured [10] water temperature.

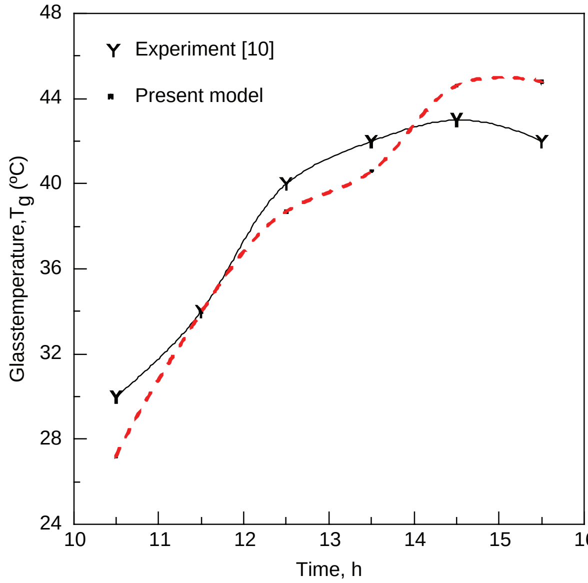

Fig. 4b. Fig. 3a: A comparison between calculated and measured [10] glass temperature.

the wind speed at different times of the day but these values were not reported [10]. Therefore, a representative value of 6 m/s was assumed and used in the present calculations. It is believed that if these values are provided, a more accurate estimate of the productivity rate could have been obtained.

Nijmeh et al. [10] also reported theoretical values of the productivity based on the equation provided by Duffie and Beckman [37]. In this equation, both water and glass temperature were taken from the measured values and used as input data to calculate the productivity in a steady-state manner. It should, however, be noted that the present model is a transient one that takes energy storage into account and hence both water and glass temperatures were considered unknowns and calculated through the energy balance. The calculated values of water and glass temperatures are in a very good agreement with the measured values, as shown in Figs. 4a and 4b, respectively.

The model was also validated through a comparison with the tabulated results given by Howe in his detailed transient theoretical analysis [40]. The reported solar radiation intensity, ambient temperature, wind speed and initial water temperature in addition to other still parameters were used as input data to the program. Fig. 5 shows an excellent agreement in calculating ΔT_w and glass temperature (T_g) which were selected as a sample among the reported results due to the space limitations.

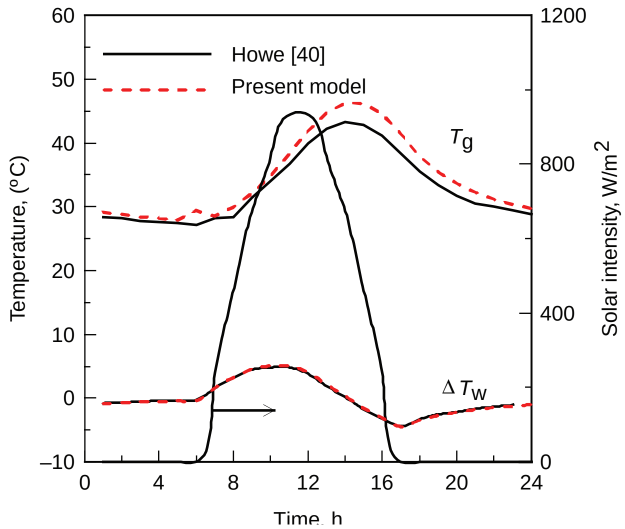

Fig. 5. Comparison of incremental basin water temperature change and glass temperature with time: comparison with Howe data [33].

2. Results and discussion

Prediction of the performance of a solar still located in Dhahran, Saudi Arabia is carried out to examine the production rate and different fractions of heat transfer rate within, into and out of the unit in this weather conditions. Furthermore, the most influential parameters that control the productivity of the solar still are pointed out so that this study may lead to design solar stills with higher productivity. The model includes variable

Table 1
Sensitivity analysis of the main controlling parameters

Parameters	Response variables							
	q_b, W/m²	q_c, W/m²	q_e, W/m²	q_{ga}, W/m²	q_r, W/m²	T_g, °C	T_w, °C	Production, ml/m²
	18.12±1.38	14.35±1.38	157.7±15.62	228.8±20.93	56.8±4.16	48.23±1.17	56.32±1.1	242.7±24.2
G (900±90), W/m²	43.02%	8.52%	37.87%	31.89%	18.87%	36.48%	67.67%	38.56%
m_s (50±5), Kg	16.61%	3.29%	14.62%	12.31%	7.29%	14.09%	26.13%	14.89%
T_a (38.2±1), °C	37.86%	24.18%	12.71%	15.01%	20.08%	14.23%	1.97%	12.44%
V (4±2), m/s	2.69%	64.01%	34.80%	40.78%	53.76%	35.20%	4.24%	34.10%
Summation	100%	100%	100%	100%	100%	100%	100%	100%

properties that are calculated and updated as functions of various temperatures. In addition, an improved formula for estimating the heat transfer coefficients, which is based on the work of Hollands et al. is used [39]. This formula was then corrected for the effect of density variation within the solar still as explained earlier in the problem formulation section.

First, the sensitivity analysis of changes in the main variables (irradiation G, seawater mass m_s, ambient temperature T_a and wind velocity V) is carried out to identify the most significant parameters that affect the solar still performance, as shown in Table 1. Expected variability was assigned to each one of the parameters (± 10% for G and m_s, ± 1 °C for T_a and ± 2 m/s for V). The corresponding effect on the main response variables (various components of heat transfer rate, glass and water temperature and solar still productivity) was monitored and the percentage weighted effect of the change is calculated using EES software [47] which has built-in capability to carry out uncertainty analysis [48,49]. For example, consider the production of the still as a response variable (last column). Changes in the productivity are influenced by the radiation heat flux (38.56%), followed by the wind speed (34.1%), the saline mass within the still (14.89%) and finally the ambient temperature (12.44%). The same argument is used for the rest of the response factors listed in the Table 1. On the other hand, wind speed is the most influential parameter on the changes in q_c, q_r and q_{ga}; while it has a negligible effect on q_b. Thus, a designer can determine the most influential parameters that control the solar still performance and can accordingly improve the unit performance.

Based on the above sensitivity study, the parameters that are used as input values to study the still performance are solar radiation intensity, ambient temperature and wind speed. Weather data of Dhahran for two days in the year representing both summer and winter seasons are used. Hourly recorded data of 17th July, 2007 were selected to represent a typical summer day, whereas data of 17th January are considered a representative winter day in the Eastern Province of Saudi Arabia.

Fig. 6 shows the heat transfer components in a summer day. Solar radiation falls into the solar still resulting in an increase in the temperature of the water in the basin, glass cover and the material of the basin itself. The heat transfer modes that are expected during the operation of still are: heat loss from the basin material to the surroundings, q_b; heat transfer from the water surface to the colder glass cover by both convection and radiation, q_c, q_r; heat transfer due to the water evaporation between the water surface and glass cover; q_e; heat transfer from the glass surface to the colder ambient air by both convection and radiation, q_{ga}.

Variation of these components is shown in Fig. 6 with time. The highest heat transfer rates recorded are corresponding to the heat loss from the glass cover to

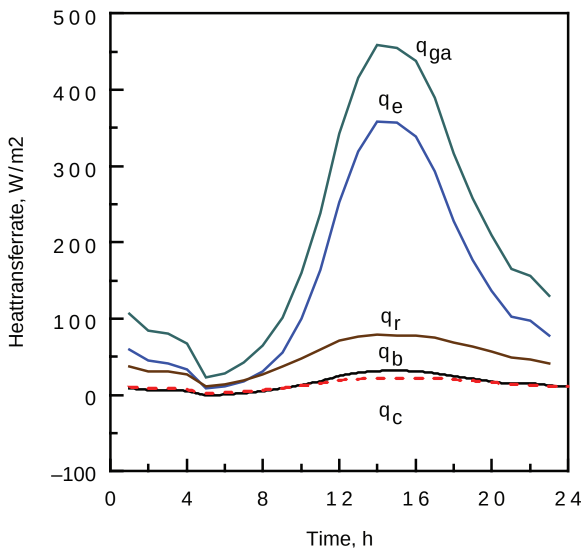

Fig. 6. Various components of heat transfer rate in a typical summer day in Dhahran.

the ambient air. It is worth mentioning that higher the value of q_{ga}, better the performance of the still is. This can be explained from the fact that more losses from the glass cover will decrease the glass temperature. This will increase the temperature difference between the water surface and glass cover, thus increasing the evaporation rate of seawater and, hence the production rate. Wind speed can be considered as an effective parameter that improves the still productivity as shown later in Fig. 11a. The high value of q_e is also favorable since it results in better water evaporation and condensation on the inner glass surface. q_b is among the lowest values and this indicates good still insulation and less heat losses through the non-glass (non-productive) part of the still. Good insulation is then an important parameter for better productivity.

Values of q follow the trend of solar radiation. These values increase from zero (sun rise) till they reach a peak value at the middle of the day and then decrease after sunset. It is important to mention that the solar still continues to produce distillate water even in the absence of the sun due to thermal storage capacity of seawater in the still that takes time to cool down. Fig. 7 shows water temperature, glass temperature, ambient temperature and solar radiation data for this day. Water and glass temperature also follow the same trend. These temperatures increase with the increase in solar radiation intensity and then decrease after sunset with a certain time lag due to the storage in water exposed to the sun radiation during the day time and relatively high ambient temperature in summer. This slows down water cooling rate and maintains the productivity. Heat transfer components shown in Fig. 8 are representing the radiation and ambient weather data calculated during the typical winter season in Dhahran. They follow the same trend as that discussed earlier in Fig. 6. However, the values are considerably less since the solar intensity during winter is much less than summer values. Therefore, as expected, the production of solar still in winter is substantially less.

The magnitudes of the calculated values of water and glass temperature (during the winter day) are shown in Fig. 9. It is clear that these values are much

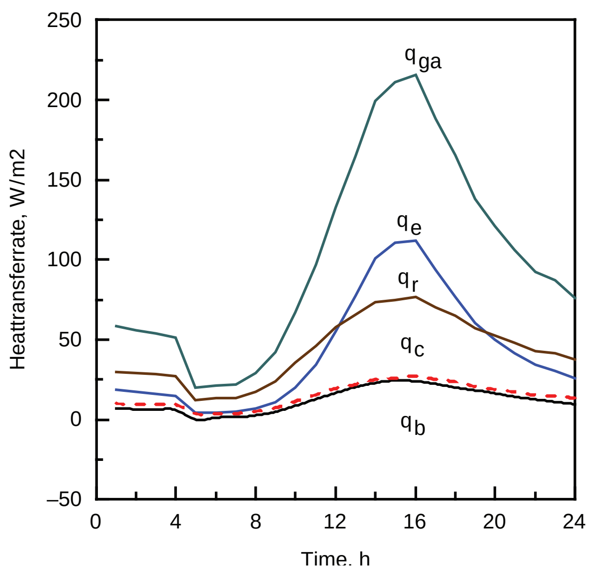

Fig. 8. Various components of heat transfer rate in a typical winter day in Dhahran.

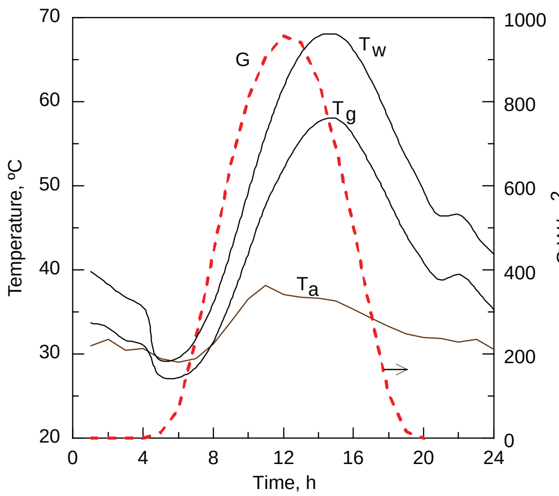

Fig. 7. Temperatures and solar radiation in a typical summer day in Dhahran.

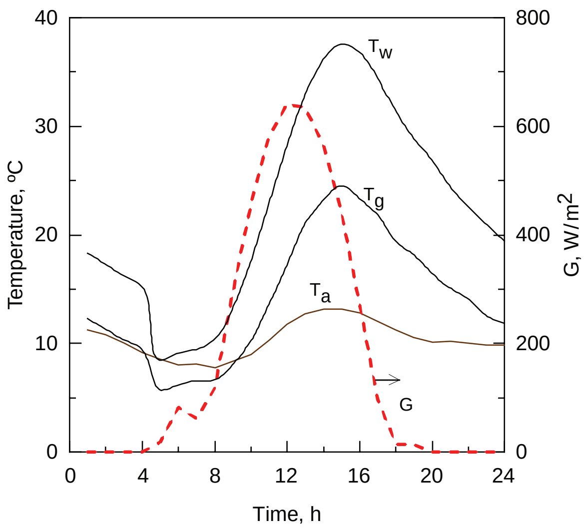

Fig. 9. Temperatures and solar radiation in a typical winter day in Dhahran.

less than those presented earlier in Fig. 7, thus much less productivity is expected during the winter period. We notice that the trends are very similar to that discussed earlier in Fig. 7. That is, they follow the solar radiation intensity pattern with a certain time lag due to thermal capacity of seawater in the basin.

The solar still productivity is depicted in Fig. 10 representing days of both summer and winter seasons.

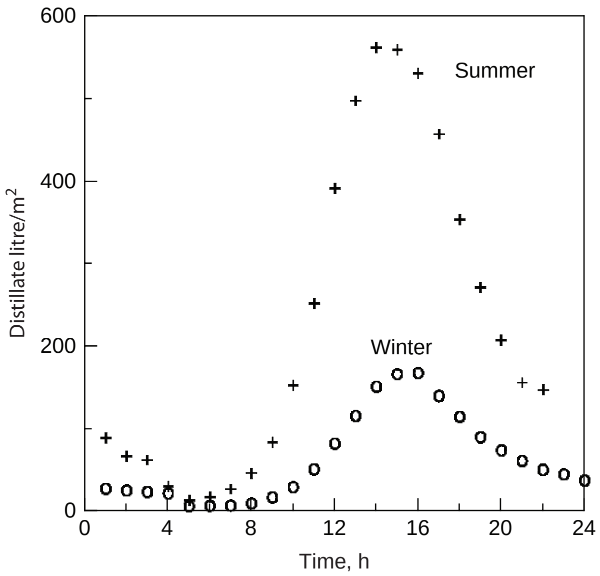

Fig. 10. Integrated hourly production for representative summer and winter days in Dhahran.

The water productivity reaches its maximum value at the midday and falls down toward early morning and after sunset. However, the production does not stop due to relatively elevated water temperature compared with both glass and ambient temperatures. Thus, a difference in vapor pressure is maintained; however, the difference in the productivity is obvious in the Figure. The cumulative distillate collected (productivity) in the summer day was 5200 ml whereas in a winter day it is 1520 ml; that is about 3.4 times increase in productivity during the peak summer period.

A parametric study was carried out to investigate the effect of main (controlling) parameters on the performance of the solar still. Results are shown in Figs. 11a and 11b. Fig. 11a shows the effect of changing the wind speed and solar radiation intensity on the solar still productivity. Changing the wind speed from 1 to 10 m/s result in 29.1% increase in the productivity of the solar still keeping the other parameters fixed whereas increasing the solar radiation intensity from 100 to 1000 W/m² results in 108.86 % increase in the solar still productivity. This Figure illustrates the effectiveness of solar radiation intensity as a key parameter affecting the still performance. This would provide guidelines to still designers to enhance the still performance using reflecting mirrors as suggested by some researchers.

Fig. 11b illustrates the effect of ambient temperature and the mass of seawater in the still which can also be expressed as the height of water within the still. Increasing the ambient temperature has an adverse

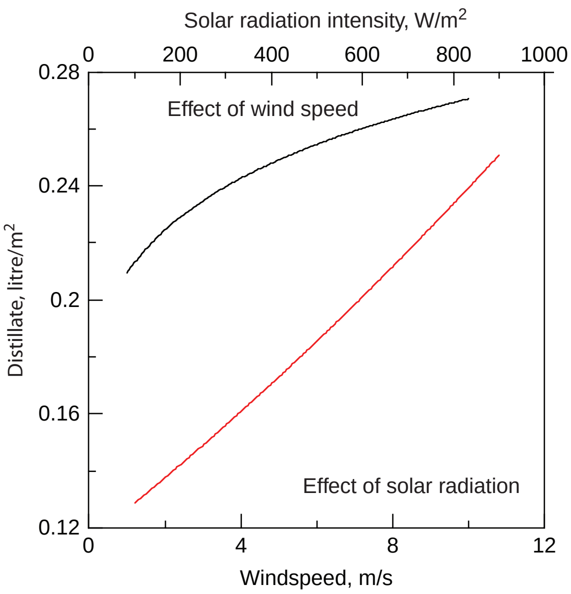

Fig. 11a. Effect of wind speed and solar radiation intensity on the solar still production.

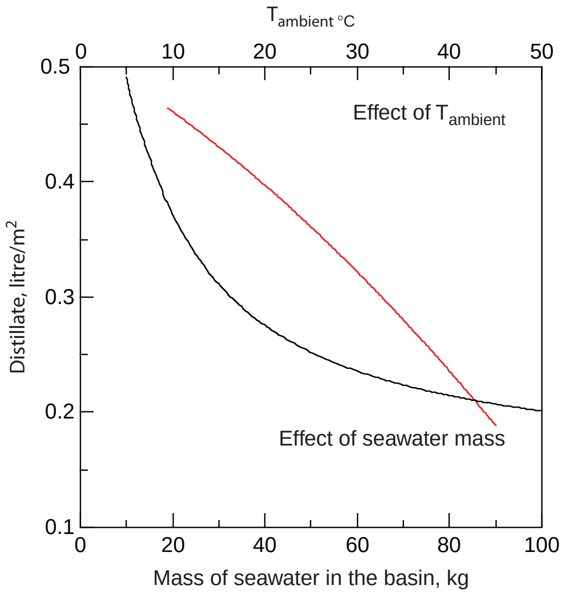

Fig. 11b. Effect of mass of seawater in the basin and ambient temperature on solar still production.

effect on the productivity as shown in the Figure. An increase of T_a from 5 (cold winter condition in this area of the Kingdom) to 45 (typical summer temperature) while the other parameters are held constant results in almost two thirds loss in water productivity. It is also noticed that about 60% of the distillate production is lost if the mass of seawater within the still is increased from 10 kg (1 cm height for a still area of 1 m^2) to 100 kg (10 cm height). Therefore, one can say that solar still production can be improved by decreasing seawater height within the still, increased wind velocity, higher solar radiation and less ambient temperature. Some of these values can be controlled during operation such as the former two parameters. The latter two parameters are harder to control since increasing solar radiation intensity can be achieved through reflecting mirrors which may raise the initial cost of the still whereas the ambient temperature is a parameter that is dictated by the ambient conditions in a given location.

3. Concluding remarks

A model was developed to predict the performance of a solar still in Dhahran, Saudi Arabia. This is a location where intense solar radiation and high ambient temperature are encountered most of the year. Therefore, it represents a suitable location for water distillation using solar energy. Still production was reported for summer and winter conditions. The model is based on classical still energy balance. However, improvements were made in terms of variable properties, a more reliable expression for calculating the heat transfer coefficient within the still that accounts for the glass surface inclination. The most important operating and ambient parameters that affect the solar still performance were identified through sensitivity analysis. It is shown that solar radiation intensity plays an important role in the solar still production through effective heating of the basin seawater that enables it to produce distillate even after sunset. Increasing wind speed is also effective in increasing the still productivity. Placing the solar still at a location of high wind speed would therefore improve its productivity. Lower ambient temperature and less water height within the still are other factors that increase the still productivity. It is expected that the results of this work would be useful as a design tool for still designers to focus on the key parameters that enhance the water production rate.

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Symbols

c_P — specific heat at constant pressure, J/kg K
F_s — radiation shape factor
G — Solar irradiation, W/m^2
h — heat transfer coefficient, W/m^2 K
h_{fg} — latent heat of evaporation (difference between the enthalpy of saturated vapor and that of saturated liquid at specified temperature), J/kg
k — thermal conductivity, W/m K
L — Distance between water surface and glass cover, m
M — molecular weight
m_D — hourly distillate collected, kg/m^2
Nu — Nusselt number
P_w — water partial pressure(at T_w), mm Hg
P_{wg} — water partial pressure(at T_g), mm Hg
q_c — convection heat transfer from water to glass cover, W/m^2
q_e — evaporation heat loss from water to glass cover, W/m^2
q_{ga} — heat transfer from the glass cover to ambient air, W/m^2
q_b — heat loss through still material to surroundings (ground), W/m^2
Ra — Rayleigh number = $g\beta\,\Delta T\, L^3/\nu\alpha$
Re — Reynolds number = $\rho_{air} Vl/\mu$
T — temperature, °C
U_b — heat transfer coefficient between the basin and surrounding soil, W/ m^2 K
V — wind speed, m/s

Subscripts

A — air (ambient)
w — water
g — glass
b — basin

Greek symbols

α — absorptivity
β — angle of inclination of glass cover
μ — dynamic viscosity of air (for Re calculation)
ν — kinematic viscosity
ρ — density
σ — Stefan Boltzmann constant
τ — transmissivity

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