Journal of Fundamentals of Renewable Energy and Applications

Tanaka, J Fundam Renewable Energy Appl 2015, 5:4
DOI: 10.4172/2090-4541.1000175

Review Article Open Access

Tilted Wick Solar Still with Flat Plate Bottom Reflector: Numerical Analysis for a Case with a Gap Between Them

Hiroshi Tanaka*

Department of Mechanical Engineering, National Institute of Technology, Kurume College, Komorino, Kurume, Japan

Abstract

A tilted wick solar still with a flat plate bottom reflector was analyzed theoretically when there is a gap between the still and reflector at 30°N latitude. A mirror-symmetric plane of the wick relative to the reflector was introduced to calculate the amount of solar radiation reflected from the reflector and absorbed on the wick. Heat and mass transfer in the still were also analyzed to determine the temperature in the still and the distillate production rate of the still. The inclinations of both the still and the reflector should be adjusted adequately for each month and for the gap length in order to increase the distillate productivity. The optimum inclinations of both the still and the reflector throughout the year were determined. The effect of the reflector on distillate productivity decreases with an increase in gap length. However, the distillate productivity can be increased by the reflector even if the gap length is equivalent to that of the still and reflector. The sum of the daily amount of distillate on each month throughout the year was predicted to be increased about 28, 19 and 14% by the reflector when the gap length is 0, 0.5 and 1 m.

Keywords: Solar desalination; Solar still; Tilted wick; Bottom reflector; Gap

Nomenclature

A: area, m^2

G: solar radiation on a horizontal surface, W/m^2

l: length, m

mc_p: heat capacity, J/K

Q_c: convective heat transfer rate, W

Q_d: conductive heat transfer rate, W

Q_e: heat transfer rate by mass transfer, W

Q_f: enthalpy increase, W

Q_r: radiative heat transfer rate, W

Q_{sun}: absorption of solar radiation, W

T: temperature, K

t: time, s

w: width, m

α: absorptance

β: incident angle of direct solar radiation on glass cover

β': incident angle of reflected solar radiation on glass cover

φ, ϕ: azimuth and altitude angle of the sun

θ: inclination angle

ρ: reflectance of reflector

τ: transmittance of glass cover

Subscripts

a: ambient air

df: diffuse radiation

dr: direct radiation

g: glass cover

gp: gap

m: reflector

re: reflected radiation

s: still

w: wick

Introduction

A tilted wick solar still consisting of a transparent cover and a wick as absorber/evaporator is one of the simplest types of solar stills. Compared with a basin type still consisting of a transparent cover and a basin liner, the advantages of the tilted wick still are as follows:

1) Heat capacity of water flowing in the wick is considerably smaller than that of water in a basin liner.

2) The inclination angle of the tilted wick still can be adjusted according to seasons and locations to increase the solar radiation absorbed on the wick, while the basin liner should be set horizontally.

3) Size of the still is smaller.

4) The tilted wick still can be installed on a slope.

Due to these advantages, tilted wick stills have been studied numerically and experimentally [1-21], and also reviewed by

***Corresponding author:** Tanaka H, Department of Mechanical Engineering, National Institute of Technology, Kurume College, Komorino, Kurume, Fukuoka 830-8555, Japan, Tel: +81-942-35-9359; Fax: +81-942-35-9321; E-mail: tanakad@kurume-nct.ac.jp

Received June 26, 2015; **Accepted** July 13, 2015; **Published** July 20, 2015

Citation: Tanaka H (2015) Tilted Wick Solar Still with Flat Plate Bottom Reflector: Numerical Analysis for a Case with a Gap Between Them. J Fundam Renewable Energy Appl 5: 175. doi:10.4172/20904541.1000175

Citation: Tanaka H (2015) Tilted Wick Solar Still with Flat Plate Bottom Reflector: Numerical Analysis for a Case with a Gap Between Them. J Fundam Renewable Energy Appl 5: 175. doi:10.4172/20904541.1000175

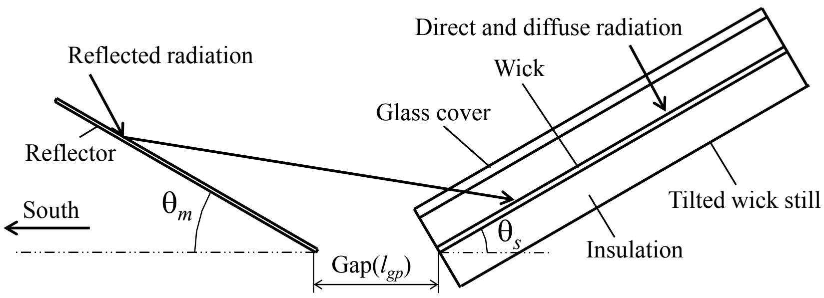

Figure 1: Schematic diagram of a tilted wick solar still with a flat plate bottom reflector with a gap between the still and reflector.

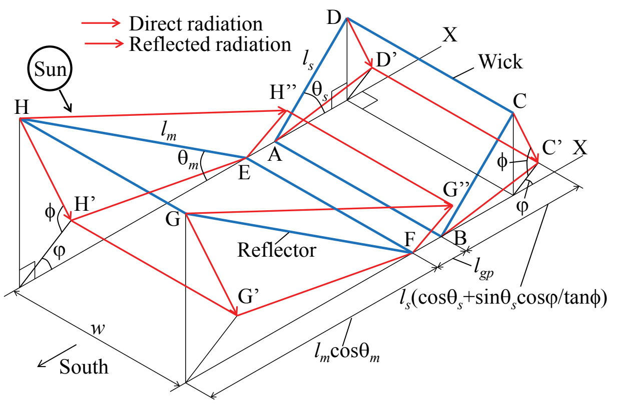

Figure 2: Direct and reflected solar radiation on the proposed still.

Manikandan et al. [22] and Murugavel et al. [23].

A flat plate reflector is an inexpensive and simple modification to increase the distillate productivity of tilted wick stills. However, there had been few reports about tilted wick stills with a flat plate reflector [3,10], and a quantitative analysis of the effect of a flat plate reflector on tilted wick stills had not been done. Tanaka and Nakatake [24-26] have presented geometrical models to predict the solar radiation reflected from a top reflector extending from the upper edge of the still, and then absorbed onto the wick. The top reflector is assumed to be set vertically in spring and autumn [24], and inclined forwards slightly in winter [25] and backwards slightly in summer [26]. Tanaka [27] also predicted the optimum inclinations of both the still and the top reflector throughout the year using these geometrical models. After that, Tanaka presented another geometrical model for a bottom reflector extending from the lower edge of the still [28], and theoretically analyzed the optimum inclinations of both the still and the bottom reflector throughout the year [29]. Through these studies, it was found that a top reflector as well as a bottom reflector can be used to increase distillate productivity of the still by adjusting the inclinations of both the still and the reflector appropriately according to the seasons.

In all the geometrical models mentioned above, it was assumed that the still and the reflector touch each other and there is no gap between them. However, in practical cases, especially when the reflector would be installed on the already mounted solar still, there would be many instances in which the reflector should be installed apart from the solar still due to limitations of the installing site. But the geometrical models which have been proposed cannot be applied if there would be any gap between the still and the reflector. Recently, Tanaka numerically analyzed a solar thermal collector and a flat plate bottom reflector with a gap between them [30], and presented a new geometrical model to predict the amount of solar radiation reflected from a bottom reflector and then absorbed on the collector in cases where there is a gap between collector and reflector. The geometrical model for a system with a gap is similar to those for stills without a gap, but more complicated. The collector/reflector system with a gap analyzed by Tanaka [30] consists of two flat plates; therefore, the geometrical model for a collector/reflector system with a gap can be applied for a tilted wick still with a flat plate bottom reflector with a gap since they are also two flat plate systems. Therefore, in this paper, the geometrical model for a collector/reflector system with a gap is applied to a tilted wick solar still with a bottom reflector with a gap between the still and reflector, and the optimum inclinations of both the still and reflector as well as an increase in distillate productivity of the still using a bottom reflector with a gap are predicted for each month of the year at 30°N.

Theoretical Analysis

Amount of solar radiation absorbed on the wick

Figure 1 shows a tilted wick solar still with a flat plate bottom reflector and a gap between the still and reflector. A tilted wick still consists of a glass cover and wick as an absorber/evaporator. The bottom of the still is insulated. The still is facing south, and the bottom reflector is placed parallel to the still at the south side of the still with a gap. It is assumed that the lower edge of the reflector and the wick of the still are at same level. The inclinations of the still and the reflector are assumed to be adjustable.

Direct and reflected solar radiation to the proposed still is shown in Figure 2. ABCD is the wick of the still and EFGH is the reflector, respectively. The walls of the still are neglected in this study since the height of the still (0.01 m) is negligible in relation to the still's length (1 m) and width (1 m). The length of the still and the reflector are shown as l_s and l_m, and the inclinations of the still and the reflector from horizontal are shown as θ_s and θ_m, respectively. The length of a gap between the still and the reflector is shown as l_{gp}. Solid arrows (CC', DD', GG' and HH') show direct radiation and dashed arrows (GG" and HH") show reflected radiation. The azimuth and altitude angle of the sun are shown as ϕ and φ, respectively.

The amount of direct solar radiation absorbed on the wick, $Q_{sun,dr}$, can be calculated by determining the area of the shadow of the wick on a horizontal surface (a trapezoid ABC'D') as

$$Q_{sun,dr} = G_{dr}\tau_g(\beta)\alpha_w \times A_{dr} \tag{1}$$

$$A_{dr} = wl_s(\cos\theta_s + \sin\theta_s\cos\phi/\tan\varphi) \tag{2}$$

$$\cos\beta = \sin\phi\cos\theta_s + \cos\phi\sin\theta_s\cos\varphi \tag{3}$$

where G_{dr} is direct solar radiation on a horizontal surface, τ_g is transmittance of the glass cover, β is the incident angle of direct solar radiation on the glass cover, α_w is absorptance of the wick and A_{dr} is the area of the wick's shadow (ABC'D'). When the sun moves north in the early morning and late evening in the months of April to August, the shadow of the wick would be shorter than $l_s\cos\theta_s$ and A_{dr} should be determined as

$$A_{dr} = wl_s(\cos\theta_s - \sin\theta_s\cos\phi/\tan\varphi) \tag{4}$$

Diffuse solar radiation absorbed on the wick, $Q_{sun,df}$, can be determined assuming that diffuse radiation comes uniformly from all directions in the sky dome, and this can be expressed as

$$Q_{sun,df} = G_{df}(\tau_g)_{df}\alpha_w \times wl_s \tag{5}$$

where G_{df} is the diffuse solar radiation on a horizontal surface, and $(\tau_g)_{df}$, which is a function of the inclination of the still, θ_s, can be calculated by integrating the transmittance of the glass cover for diffuse radiation from all directions in the sky dome [24].

The reflected projection from the bottom reflector is shown as EFG"H". Not all of the reflected radiation from the bottom reflector can reach the wick, and part or all of the reflected radiation would escape to the ground without hitting the wick. To calculate the amount of solar radiation reflected from the bottom reflector and then absorbed on the wick, a mirror-symmetric plane of the wick relative to the reflector is introduced. A side view of the wick, reflector and mirror-symmetric plane is shown in Figure 3. BC and FG show the wick and reflector, and JK shows the mirror-symmetric plane. As shown, the position of the upper edge of the mirror-symmetric plane (point J) can be determined using lengths l_1 and l_2.

$$l_1 = 2l_{gp}\sin^2\theta_m \tag{6}$$

$$l_2 = 2l_{gp}\sin\theta_m\cos\theta_m = l_{gp}\sin 2\theta_m \tag{7}$$

The incident point and incident angle of the reflected radiation on the wick are exactly the same as those of the direct radiation which goes through the reflector and incidents on the mirror-symmetric plane. Therefore, the amount of the reflected radiation absorbed on the wick can be calculated by determining the amount of direct radiation which goes through the reflector and then is absorbed on the mirror-symmetric plane. Here, ω_1 is the inclination from vertical of the mirror-symmetric plane determined as

$$\omega_1 = 2\theta_m + \theta_s - \pi/2 \tag{8}$$

Figure 3 shows only case in which ω_1 is positive. If ω_1 is negative,

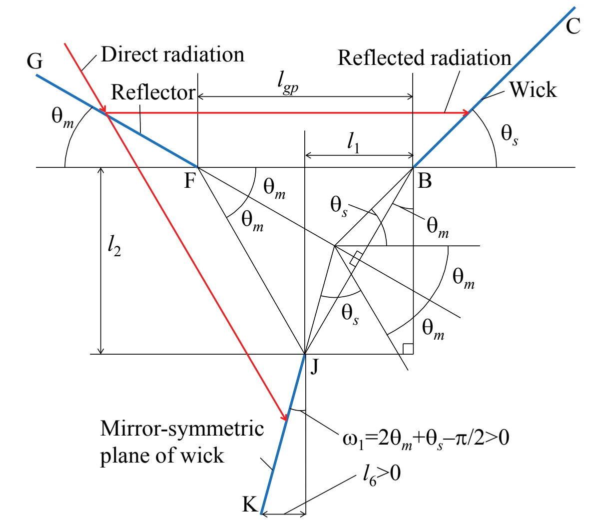

Figure 3: A side view of the wick, reflector, and a mirror-symmetric plane of the wick relative to the reflector.

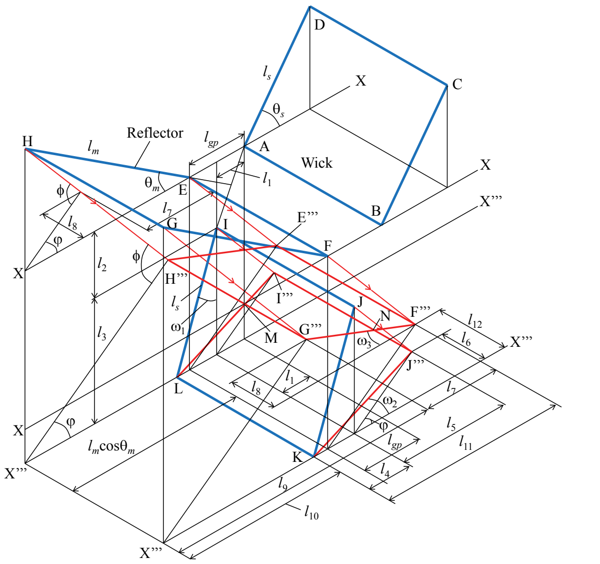

Figure 4: Geometrical model to determine the amount of solar radiation which goes through the reflector and is absorbed on a mirror-symmetric plane.

length l_6 mentioned below will also be negative, however, the following calculations are valid even if ω_1 and l_6 have negative values.

A geometrical model to calculate the amount of direct radiation which goes through the reflector and is absorbed on the mirror-symmetric plane is shown in Figure 4. The wick of the still (shown as ABCD) and the reflector (shown as EFGH) are exactly the same as those shown in Figure 2. A mirror-symmetric plane shown as IJKL is placed on a virtual horizontal surface X''' which is l_2+l_3 below the horizontal surface X on which the still and reflector are placed. The shadows of the reflector (EFGH) and the mirror-symmetric plane (IJKL) caused by direct radiation on a virtual horizontal surface X''' are shown as E'''F'''G'''H''' and I'''J'''KL, respectively. Therefore, the amount of direct radiation which goes through the reflector and is absorbed on the mirror-symmetric plane, which is exactly the same as that reflected from the reflector and then absorbed on the wick, $Q_{sun,re}$, can be calculated by determining the area of the overlapping part of these shadows (A_{re}) shown as I'''NG'''M. This can be expressed as

$$Q_{sun,re} = G_{dr}\rho_m \tau_g(\beta')\alpha_w \times A_{re} \qquad (9)$$

$$\cos\beta' = \sin\phi\cos\omega_1 + \cos\phi\sin\omega_1\cos\varphi \qquad (10)$$

where ρ_m is reflectance of the reflector and β' is incident angle of the reflected radiation on the glass cover. Here, lengths l_3 to l_{12} and angles ω_2 and ω_3 shown in Figure 4 to calculate the overlapping area can be determined as follows:

$$l_3 = l_s\cos\omega_1 \qquad (11)$$

$$l_4 = l_s\sin\omega_1 \qquad (12)$$

$$l_5 = l_3\cos\varphi/\tan\phi \qquad (13)$$

$$l_6 = l_3\sin|\varphi|/\tan\phi \qquad (14)$$

$$l_7 = l_m(\cos\theta_m - \sin\theta_m\cos\varphi/\tan\phi) \qquad (15)$$

$$l_8 = l_m\sin\theta_m\sin|\varphi|/\tan\phi \qquad (16)$$

$$l_9 = (l_m\sin\theta_m + l_2 + l_3)\cos\varphi/\tan\phi \qquad (17)$$

$$l_{10} = l_m\cos\theta_m + l_{gp} - l_1 - l_4 \qquad (18)$$

$$l_{11} = l_9 + l_7 - l_{10} \qquad (19)$$

$$l_{12} = (l_2 + l_3)\sin|\phi|/\tan\varphi \qquad (20)$$

$$\tan\omega_2 = l_6/(l_4 + l_5) \qquad (21)$$

$$\tan\omega_3 = l_8/l_7 \qquad (22)$$

The overlapping area A_{re} should be calculated according to the conditions of the positions of shadows of both the reflector and mirror-symmetric plane, and the calculating methods were described in detail in a previous paper [30].

Effect of shadow of reflector on wick

When the solar altitude angle φ is small in the early morning and late evening, the reflector will shade the wick and this will cause decrease in direct radiation absorbed on the wick, especially in the case where the inclination of the reflector θ_m is large. In the calculations, the effect of the shadow is taken into consideration. The way to estimate the effect of the shadow was described in a previous paper in detail [30]. Here, the effect of the shadow is also affected by a gap length l_{gp} and decreases with an increase in gap length l_{gp} as mentioned in Results.

Heat and mass transfer in the still

The wick of the still absorbs solar radiation ($Q_{sun,w}$). A part of the energy escapes to the surroundings through the bottom insulation by conduction (Q_d), and is consumed to heat up saline water fed to wick (Q_f). The remaining energy transfers to the glass cover by radiation (Q_r), conduction and mass transfer (Q_e). Therefore, energy balance for the wick can be expressed as

$$Q_{sun,w} = Q_{(r+d+e),w-g} + Q_{d,w-a} + Q_f \qquad (23)$$

where subscripts *w*, *g* and *a* show the wick, glass and ambient air, respectively. Subscripts of Q, e.g. *w–g*, show the heat transfer rate from the wick (*w*) to the glass cover (*g*).

The glass cover of the still absorbs solar radiation ($Q_{sun,g}$) as well as heat transfer from the wick, and the energy is transferred to the surroundings by radiation and convection (Q_c). Therefore, energy balance for the glass cover can be expressed as

$$Q_{sun,g} + Q_{(r+d+e),w-g} = Q_{(r+c),g-a} + (mc_p)_g\frac{dT_g}{dt} \qquad (24)$$

Htin the calculations, and mc_p is heat capacity, *T* is temperature and *t* is time. Each heat transfer rate in Eqs. (23) and (24) was described in a previous paper in detail [28].

Solar radiation absorbed on the wick, $Q_{sun,w}$, and the glass cover, $Q_{sun,g}$, can be expressed as

$$Q_{sun,w} = Q_{sun,dr} + Q_{sun,df} + Q_{sun,re} \qquad (25)$$

$$Q_{sun,g} = \left(Q_{sun,dr}/\tau_g(\beta) + Q_{sun,df}/(\tau_g)_{df} + Q_{sun,re}/\tau_g(\beta')\right)\times\alpha_g/\alpha_w \qquad (26)$$

where α_g is absorptance of the glass cover.

Eqs. (1) to (26) and relating equations were solved together to find the solar radiation absorbed on the wick and the glass cover, temperatures of the wick and the glass cover and distillate production rate of the still with 600 s time steps. Temperatures of the wick and the glass cover were set to be equal to ambient air temperature at *t* = 0 just before sunrise as the initial condition. The weather and design conditions and physical properties employed in the calculations are listed in Table 1.

Results

Figure 5 shows theoretical predictions of hourly variations in (a) global solar radiation on a 1 m^2 horizontal surface and distillate production rate of a tilted wick still and (b) direct ($Q_{sun,dr}$), diffuse ($Q_{sun,df}$) and reflected ($Q_{sun,re}$) solar radiation absorbed on the wick on a spring equinox day. The daily global solar radiation on this day is about 23.3 MJ/m^{2}day. Here, the inclination of the still θ_s is determined as 35° which maximizes the distillate production rate of the still when there is no gap between the still and reflector and the reflector's length l_m is the same as still's length l_s on that day [29]. In Figure 5, the results for a still with a reflector (RS), in which the reflector's inclination θ_m is 30° and 40° and gap length l_{gp} is 0, 0.5 and 1 m as well as a still without a reflector (NS) are shown. The distillate production rate as well as each solar radiation absorbed on the wick varies similarly with the change in global solar radiation. The distillate production rate and reflected solar radiation absorbed on the wick for RS is larger for θ_m = 30° than for θ_m = 40°, and decreases with an increase in gap length l_{gp} for both inclinations θ_m. When the reflector inclination θ_m is 40° and gap length l_{gp} is 1 m, the wick cannot absorb the reflected radiation and the distillate

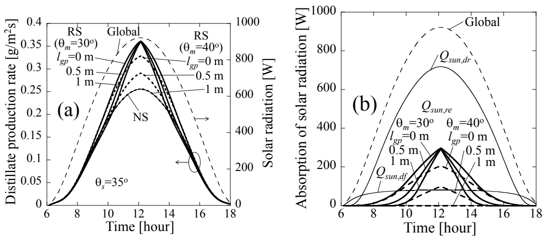

Figure 5: Time variations of (a) the distillate production rate of the still (RS is a still with a reflector and NS is one without a reflector) and global solar radiation on a horizontal surface and (b) absorption of solar radiation on the wick at θ_s = 35º on a spring equinox day.

production rate is the same as NS throughout the day. This indicates that the inclinations of both the still and reflector should be determined carefully when the gap is large. When the reflector's inclination θ_m = 30º, the distillate production rate as well as reflected radiation absorbed on the wick decreases with an increase in gap length l_{gp}, however, at noon, these figures are almost the same at any gap length l_{gp}. The reason is as follows: the altitude angle of the sun φ at noon on this day is about 60º, and reflected radiation from the reflector with an inclination of 30º goes nearly horizontal. Therefore, the effect of the gap length would be very little or negligible at noon.

The global solar radiation on a 1 m² horizontal surface and distillate production rate on the summer solstice (daily global solar radiation is about 30.3 MJ/m²day) and winter solstice (daily global solar radiation is 12.6 MJ/m²day) are shown in Figures 6 and 7. The still's inclination θ_s is determined as 10º or 65º on the summer and winter solstices, respectively, due to the same reason as on the spring equinox. On both days, the distillate production rate can be increased by using a flat plate bottom reflector even if the gap length is equivalent to the lengths of both the still and reflector (1 m). These results indicate that a flat plate bottom reflector can be used effectively even if there is a gap between the still and reflector throughout the year by adjusting both the inclinations of the still and the reflector.

Isometric diagrams of the daily amount of distillate produced by the still (kg/m²day) varying with both the inclinations of the still and reflector on the spring equinox and summer and winter solstices are shown in Figure 8. The daily amount of distillate of each figure in Figure 8 was calculated at 1º steps for each inclination θ_s and θ_m. The daily amount of distillate of NS with θ_s = 30º on each day is also shown in Figure 8. The inclinations θ_s and θ_m which maximize the daily amount of distillate vary considerably with the seasons, and are slightly affected by gap length l_{gp}. The inclination of the still θ_s which results in the maximum daily amount of distillate is largest in winter and smallest in summer, while the inclination of the reflector θ_m which results in the maximum daily amount of distillate is largest in summer and smallest in winter, since the solar altitude angle is highest in summer and lowest in winter. The range of the reflector's inclination θ_m which can increase the daily amount of distillate decreases with an increase in gap length l_{gp} from about ± 20º at l_{gp} = 0 m to about ± 10º at l_{gp} = 1 m. Therefore, the reflector's inclination θ_m should be adjusted to the proper angle more carefully when the gap length is long. When the gap length l_{gp} = 0 m, a considerable decrease in daily amount of distillate is observed when the reflector's inclination is large, especially in spring and winter. This is due to the shadow of the reflector on the wick. However, the effect of the shadow of the reflector decreases with an increase in gap length l_{gp} since the shadow of the reflector does not reach the wick when the gap is large.

The combinations of the optimum inclinations of the still (θ_s) and the reflector (θ_m) which result in the maximum daily amount of distillate on each month throughout the year are shown in Figure 9. The optimum inclination of the still without a reflector (NS) is also shown. The optimum inclinations of both θ_s and θ_m are approximately symmetrical with the months of June and December.

In winter, the optimum inclination of the still θ_s slightly decreases and of the reflector θ_m slightly increases with an increase in gap length l_{gp}. The reason is as follows: the altitude angle of the sun at noon on the winter solstice is about 36º, and the reflected radiation from the reflector inclined at θ_m is around 10º goes upwards. And the angle from horizontal of the reflected radiation can be decreased by increasing the reflector's inclination. Therefore, the reflector's inclination should be increased with an increase in gap length l_{gp} to hit the reflected radiation on the wick. When the gap length l_{gp} is short, an increase in absorption of reflected radiation overcomes a decrease in direct radiation absorbed on the wick by increasing the still's inclination θ_s from the optimum one of NS. However, this effect decreases with an increase in gap length l_{gp}. Therefore, the optimum inclination of the still slightly decreases with an increase in gap length l_{gp} and comes close to that of NS.

In summer, especially in June, the optimum inclination of the still θ_s is not affected by the gap length l_{gp}, while the optimum inclination of the reflector θ_m slightly decreases with an increase in gap length l_{gp}. The reason is as follows: the altitude angle of the sun at noon on a summer solstice day is about 83º, and the reflected radiation from the reflector with inclination θ_m at around 50º goes downwards. The angle from horizontal of the reflected radiation can be decreased by decreasing the reflector's inclination. Therefore, the reflector's inclination should be decreased with an increase in gap length l_{gp} to hit the reflected radiation on the wick.

The optimum inclinations of both the still θ_s and the reflector θ_m, which are determined in 5º steps for ease of operation, are listed in Table 2. Here, the deviation of the daily amount of distillate obtained with θ_s and θ_m listed in Table 2 compared with that obtained with θ_s and θ_m shown in Figure 9 is less than 1 %. Therefore, the approximate maximum daily amount of distillate can be obtained with inclinations θ_s and θ_m listed in Table 2.

The variations of the daily amount of distillate throughout the year and the cumulative productivity (sum of the daily amount of distillate on each month in Figure 10) with gap length l_{gp} are shown in Figures 10 and 11. Here, NS shows the results of a still without a reflector in which the still's inclination is fixed at 30º throughout the year, and NS* shows the results for one in which the still's inclination is set to the optimum listed in Table 2 according to month. The daily amount of distillate can be increased by the flat plate bottom reflector throughout the year even if there is a gap between the still and the reflector, and the cumulative productivity of the still with reflector is predicted to be about 81.2, 75.6 and 72.4 kg/m², and about 28, 19 and 14 % more than that of NS (63.3 kg/m²) when the gap length l_{gp} is 0, 0.5 and 1 m. However, the daily amount of distillate and the range of the inclination of the reflector that can increase the daily amount of distillate decreases with an increase in gap length l_{gp}. Therefore, it is better to set the reflector nearer to the still.

Conclusions

The effect of a flat plate bottom reflector on the distillate production rate of a tilted wick solar still was analyzed theoretically for instances when there is a gap between the still and reflector. The results of this

Citation: Tanaka H (2015) Tilted Wick Solar Still with Flat Plate Bottom Reflector: Numerical Analysis for a Case with a Gap Between Them. J Fundam Renewable Energy Appl 5: 175. doi:10.4172/20904541.1000175

G_{dr}, G_{df}: Bouger's and Berlage's equations [31] with transmittance of atmosphere of 0.7, solar radiation incident on the atmosphere of 1370 W/m² at 30°N latitude.
Ambient air temperature: 25 °C (Feb., March and April), 33 °C (May, June and July), 30 °C (Aug., Sep. and Oct.) and 20 °C (Nov., Dec. and Jan.).
Wind velocity of ambient air = 1 m/s $l_s = l_m = w = 1$ m, $\rho_m = 0.85$, $\alpha_w = 0.9$, $\alpha_g = 0.08$
Diffusion gap between the wick and the glass cover = 10 mm.
Thickness and thermal conductivity of bottom insulation = 50 mm and 0.04 W/mK.
Transmittance of glass cover [32]: $\tau_g(\beta) = 2.642\cos\beta - 2.163\cos^2\beta - 0.320\cos^3\beta + 0.719\cos^4\beta$ ·
Feeding rate of saline water to the wick: Twice as large as the steady-state evaporation rate from the wick calculated on the assumption that solar radiation is kept constant at its peak value throughout the local day time.

Table 1: The weather and design conditions and physical properties.

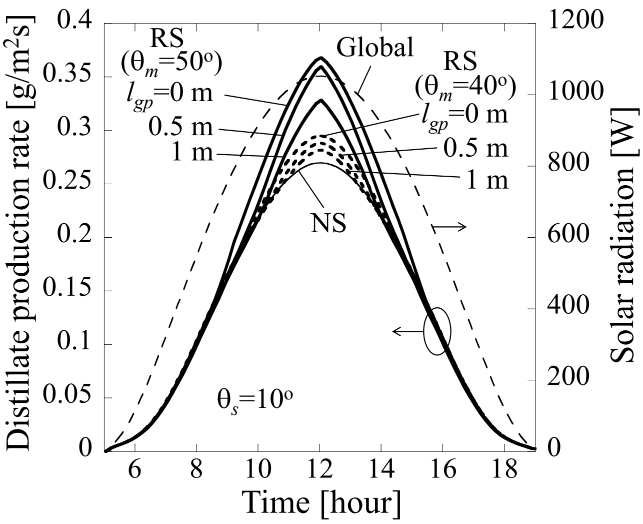

Figure 6: Time variations of the distillate production rate of the still and global solar radiation on a horizontal surface at θ_s = 10° on a summer solstice day.

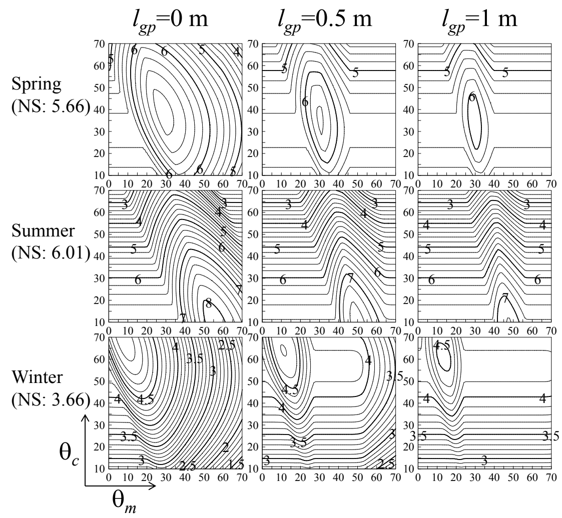

Figure 8: Isometric diagrams of the daily amount of distillate (kg/m²day) varying with both the inclinations of the still θ_s and reflector θ_m at l_{gp} = 0, 0.5 and 1 m on three typical days (spring equinox and summer and winter solstices).

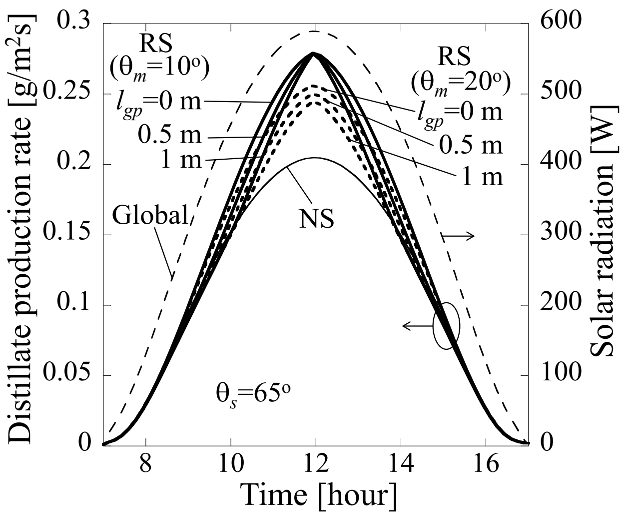

Figure 7: Time variations of the distillate production rate of the still and global solar radiation on a horizontal surface at θ_s = 65° on a winter solstice day.

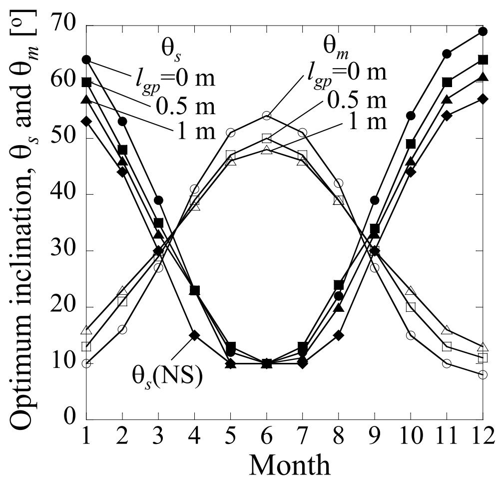

Figure 9: Combinations of the optimum inclinations of the still and reflector which maximize the daily amount of distillate throughout the year.

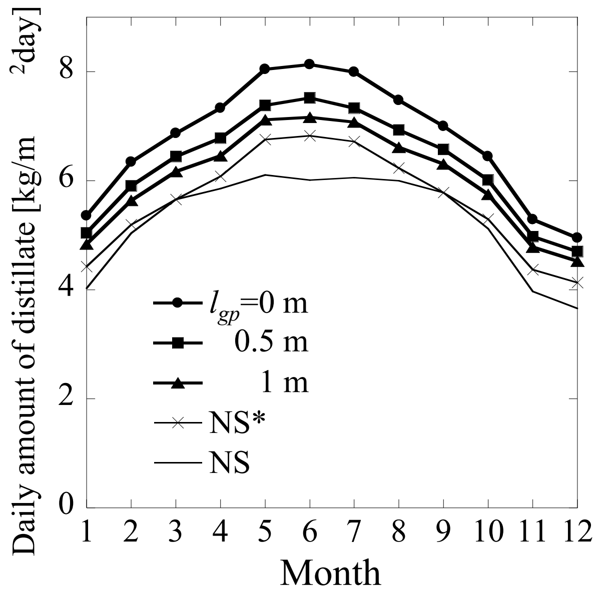

Figure 10: Daily amount of distillate varying with the gap length l_{gp} throughout the year.

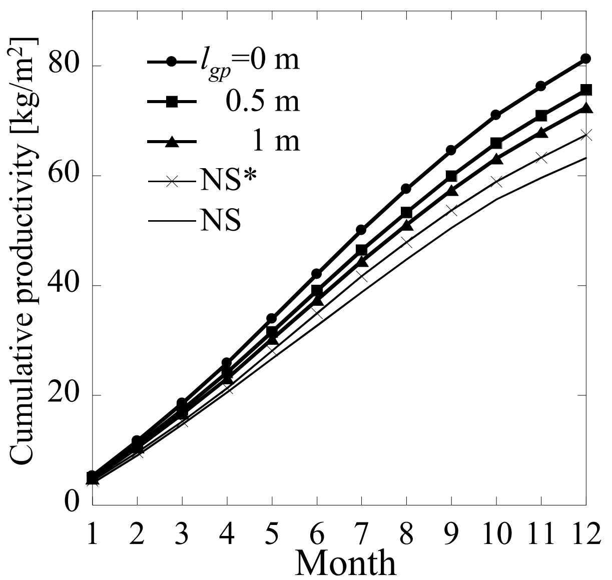

Figure 11: Cumulative daily amount of distillate on each month varying with the gap length l_{gp}.

work are summarized as follows:

(1) The distillate productivity of the still can be increased by a flat plate bottom reflector throughout the year even if the gap length is equivalent to the length of the still and reflector.

(2) The optimum inclinations of both the still and reflector are considerably affected by seasons, and slightly affected by the gap lengths.

(3) The optimum inclination of the still is highest in winter and lowest in summer, while the optimum inclination of the reflector is lowest in winter and highest in summer.

t	NS	RS (l_{gp} [m])					
		0		0.5		1	
	θ_s	θ_s	θ_m	θ_s	θ_m	θ_s	θ_m
Dec.	55	65	10	65	10	60	15
Jan., Nov.	55	65	10	60	15	55	15
Feb., Oct.	45	55	15	50	20	50	20
Mar., Sep.	30	35	30	35	30	35	30
Apr., Aug.	15	25	40	20	40	20	40
May, July	10	15	50	15	45	10	45
June	10	10	55	10	50	10	45

Table 2: Optimum inclinations of still θ_s and reflector θ_m throughout the year at 5° steps.

(4) Both the inclinations of the still and reflector should be adequately adjusted according the seasons, especially when the gap is large.

(5) The distillate productivity of the still decreases with an increase in gap length even though both the inclinations of the still and reflectors are set to the proper angle.

(6) The sum of the daily amount of distillate of the still on each month throughout the year was predicted to increase about 28, 19 and 14% due to the reflector when the gap length is 0, 0.5 and 1 m, respectively.

References

1. Tanaka K, Yamashita A, Watanabe K (1981) Experimental and analytical study of the tilted wick type solar still. International Solar Energy Society Congress, Brighton: 1087-1091.
2. Sodha MS, Kumar A, Tiwari GN, Tyagi RC (1981) Simple multiple wick solar still: Analysis and performance. Solar Energy 26: 127-131.
3. Malik MAS, Tiwari GN, Kumar A, Sodha MS (1982) Solar Distillation. Pergamon Press, UK.
4. Gandhidasan P (1983) Theoretical study of tilted solar still as a regenerator for liquid desiccants. Energy Convers Manag 23: 97-101.
5. Tiwari GN, Sharma SB, Sodha MS (1984) Performance of a double condensing multiple wick solar still. Energy Convers Manag 24: 155-159.
6. Tiwari GN (1984) Demonstration plant of multi wick solar still. Energy Convers Manag 24: 313-316.
7. Yeh HM, Chen LC (1986) The effect of climatic, design and operational parameters on the performance of wick-type solar distillers. Energy Convers Manag 26: 175-180.
8. Mahdi JT, Smith BE (1994) Solar distillation of water using a V-trough solar concentrator with a wick-type solar still. Renew Energy 5: 520-523.
9. Minasian AN, Al-Karaghouli AA (1995) An improved solar still: The wick-basin type. Energy Convers Manag 36: 213-217.
10. Al-Karaghouli AA, Minasian AN (1995) A floating-wick type solar still. Renew Energy 6: 77-79.
11. Hongfei Z, Xinshi G (2002) Steady-state experimental study of a closed recycle solar still with enhanced falling film evaporation and regeneration. Renew Energy 26: 295-308.
12. Aybar HS, Egelioglu F, Atikol U (2005) An experimental study on an inclined solar water distillation system. Desalination 180: 285-289.
13. Janarthanan B, Chandrasekaran J, Kumar S (2005) Evaporative heat loss and heat transfer for open- and closed-cycle systems of a floating tilted wick solar still. Desalination 180: 291-305.
14. Boukar M, Harmim A (2005) Performance evaluation of a one-sided vertical

solar still tested in the desert of Algeria. Desalination 183: 113-126.

15. Shukla SK, Sorayan VPS (2005) Thermal modeling of solar stills: An experimental validation. Renew Energy 30: 683-699.
16. Eltawil MA, Zhengming Z (2009) Wind turbine-inclined still collector integration with solar still for brackish water desalination. Desalination 249: 490-497.
17. Mahdi JT, Smith BE, Sharif AO (2011) An experimental wick-type solar still system: Design and construction. Desalination 267: 233-238.
18. Omara ZM, Eltawil MA, ElNashar EA (2013) A new hybrid desalination system using wicks/solar still and evacuated solar water heater. Desalination 325: 56-64.
19. Alvarado-Juarez R, Alvarez G, Xaman J, Hernandez-Lopez I (2013) Numerical study of conjugate heat and mass transfer in a solar still device. Desalination 325: 84-94.
20. Zerrouki M, Settou N, Marif Y, Belhadj MM (2014) Simulation study of a capillary film solar still coupled with a conventional solar still in south Algeria. Energy Convers Manag 85: 112-119.
21. Hansen RS, Narayanan CS, Murugavel KK (2015) Performance analysis on inclined solar still with different new wick materials and wire mesh. Desalination 358: 1-8.
22. Manikandan V, Shanmugasundaram K, Shanmugan S, Janarthanan B, Chandrasekaran J (2013) Wick type solar stills: A review. Renew Sustain Energy Rev 20: 322-335.
23. Murugavel KK, Anburaj P, Hanson RS, Elango T (2013) Progresses in inclined type solar stills. Renew Sustain Energy Rev 20: 364-377.
24. Tanaka H, Nakatake Y (2007) Improvement of the tilted wick solar still by using a flat plate reflector. Desalination 216: 139-146.
25. Tanaka H, Nakatake Y (2009) Increase in distillate productivity by inclining the flat plate external reflector of a tilted-wick solar still in winter. Solar Energy 83: 785-789.
26. Tanaka H (2011) Increase in distillate productivity by inclining the flat plate reflector of a tilted-wick solar still in summer. Energy Sci Technol 1: 11-20.
27. Tanaka H (2009) Tilted wick solar still with external flat plate reflector: Optimum inclination of still and reflector. Desalination 249: 411-415.
28. Tanaka H (2011) Tilted wick solar still with flat plate bottom reflector. Desalination 273: 405-413.
29. Tanaka H (2013) Optimum inclination of still and bottom reflector for tilted wick solar still with flat plate bottom reflector. Desalin Water Treat 51: 6482-6489.
30. Tanaka H (2015) Theoretical analysis of solar thermal collector and flat plate bottom reflector with a gap between them. Energy Reports 1: 80-88.
31. Japan Solar Energy Society (1985) Solar Energy Utilization Handbook, Onkodo Press, Tokyo.
32. Tanaka H, Nosoko T, Nagata T (2000) A highly productive basin-type – multiple-effect coupled solar still. Desalination 130: 279-293.