RESEARCH NOTE

COMPUTER SIMULATION OF THE PERFORMANCES OF SOLAR PONDS IN IRAN

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Abstract The Rab1-Nielsen formulas are used to make predictions for solar pond operations for four locations situated in different solar insolation zones in Iran. The inputs to the computer program for determining the temperature variation at the bottom of the pond are the total insolation (corrected for cloudiness), ambient temperature, insolating layer thickness, convecting layer thickness and load. The mean, the amplitude of the varying part, and the phase of the temperature at the bottom is the output of the program. The computer simulations show that solar ponds may be promising as solar collectors for space heating in most parts of Iran.

چکیده عملکرد حوضچه های خورشیدی درچهار ناحیه ایران که دارای تابش خورشید متفاوتی میباشند توسط فرمولهای رابل-نلسون بررسی شده است. اطلاعات ورودی به برنامه کامپیوتری جهت توزیع دما در قسمت تحتانی حوضچه های خورشیدی شامل مقدار کل تابش خورشید (برمبنای میزان ابر)، دمای محیط، ضخامت لایه عایق، ضخامت لایه جابجایی و بار گرمایش میباشند. خروجی های برنامه کامپیوتری شامل مقدار دامنه تغییرات در دما، مقدار متوسط دماو فواصل تغییرات آن میباشند. مشابه سازی کامپیوتری و پاسخهای بدست آمده بیانگر آن است که حوضچه های خورشیدی به خوبی می توانند بصورت گیرنده و جمع کننده انرژی خورشیدی جهت گرمایش ساختمانها در بسیاری از مناطق ایران بکار گرفته شوند.

INTRODUCTION

Salt gradient solar ponds as a means of collecting and storing solar energy have been known for years [1]. Normally a solar pond (Figure 1) consists of three water layers: a relatively thin homogeneus and convective fresh water surface layer; a non-convecting layer in the middle, a meter or more thick, in which there are gradients in salinity (increasing downwards) and temperature (hot on the bottom, cold on the top); and a lower homogeneous-high salinity convecting layer, also a meter or so thick, which serves as a storage layer for solar radiation. Both direct and diffused solar radiation penetrate throughout the pond. Even though very little radiation of solar spectrum wavelength longer than 0.7 micrometer penetrates through as much as one meter of water, the short and medium wavelengths are absorbed throughout the pond and on the black bottom. The thermal radiation from the bottom in the long wavelengths is strongly absorbed in the lower convectine layer, where the heat is trapped since the upper layer is non-convecting and water is a very poor conductor.

In this study, the Rabl-Nielson (R.N.) formulas [2] are applied to the conditions in four locations with different insolation rates in Iran to make predictions for solar ponds

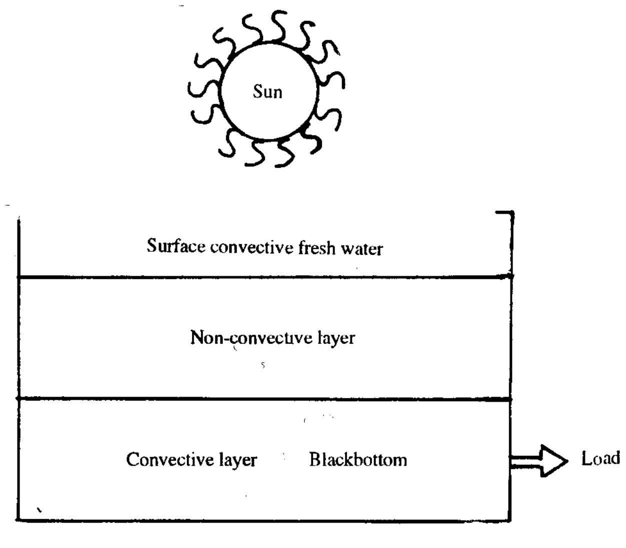

Figure 1. .ayout of the solar pond.

TABLE 1. Mean Monthly Total Daily Solar Radiation Incident upon a Horizontal Surface, Corrected for Cloudiness, (Wm^2 - day), adopted from Ref. [3].

City	Rasht	Mashhad	Tehran	Shiraz
March	108	164	188	219
April	162	226	238	268
May	195	276	282	301
June	204	294	291	300
July	180	285	276	286
August	140	237	237	264
Sebtember	105	178	185	227
October	72	119	126	167
November	50	82	90	127
December	45	78	84	123
January	57	95	107	147
February	76	122	97	189

operations. The computer program, developed for a R.N.-two layer (upper non-convecting and lower convecting) solar pond, determines the temperature on the bottom of the pond as a function of time with solar, insolation, ambient temperature, convecting layer and non-convecting layer thickness and load, as parameters.

TABLE 2. Location, Insolation and, Climate.

Location, latitute, and Cost	Insolation $\bar{H}$ (W/m²)	Insolation $\tilde{H}$ (W/m²)	Air temperature $\bar{T}_a$ (°C)	Air temperature $\tilde{T}_a$ (°C)	Air temperature δ_a (rad)
Rasht, 37.32, 0.839	116.18	79.01	15.4	9.4	0.493
Mashhad, 36.27, 0.843	179.80	110.40	13.5	11.4	0.493
Tehran, 35.68, 0.846	183.47	108.88	16.8	12.7	0.493
Shiraz, 29.53, 0.869	217.96	90.05	17.5	10.6	0.493

THEORY

In his recent study of the solar energy for Iran, Samimi[3] calculates the mean monthly total daily solar radiation, corrected for cloudiness, for a number of cities. According to his calculations the total (direct plus diffused) solar energy flux, H(θ), incident upon horizontal surface can be described by

$$H(\theta) = [s + 0.1\,s + 0.3\,(1 - s)]\, I(\theta) \cos(\theta) \qquad (1)$$

where θ,s and I(θ) are the solar altitude angle, the ratio of the number of sunny hours to the total sunny hours avail-

TABLE 3. Pond Parameters for an Average Year for Four Cities in Iran

Location	Insulating layer2 l_i	Convecing layer lc	Heat load $\bar{S}$	Average temp $\bar{T}$	Temp.amplitute $\tilde{T}$	Phase $\bar{\delta}$
	100 (cm)	100 (cm)	0 (W/m²)	84.5 (°C)	17.3 (°C)	1.10 (rad)
		100			12.5	1.28
		300			9.6	1.38
		100	23.25	45.8	29.2	1.25
		200			21.1	1.43
		300			16.2	1.53
	100	100	0	120.6	24.2	1.05
		200			17.4	1.24
Mashhad		300			13.5	1.34
		100	35.96	60.8	43.1	1.12
		200			31.1	1.30
		300			24.0	1.40
	100	100	0	126.1	24.3	1.06
		200			17.5	1.25
		300			13.5	1.35
		100	36.69	65.	43.6	1.12
		200			31.5	1.31
		300			24.3	1.41
	100	100	0	148.1	20.2	1.06
		200			14.6	1.25
Shiraz		300			11.2	1.35
			43.59	75.6	43.2	1.14
		200			31.2	1.32
		300			24.1	1.42

able, and the direct energy flux, respectively, In this equation it is simply assumed that the diffused solar flux is 10 percent for sunny days and 30 percent for cloudy days of the direct solar energy flux. The calculations of the mean monthly total daily solar radiation is then made by empolying Equation (1) and summing over days in each month

$$H = \sum_{days} H(\theta) / (\text{Number of days in each month}) \quad (2)$$

Samimi's calculations of the mean monthly total daily insolation agree very well with the measured values for Tehran and are assumed to do so for other cities [3]. His results for four locations: Rasht in low radiation zone (less than 350 cal/cm^2-day). Mashhad in intermediate radiation zone (350 to 390 cal/cm^2 - day), Tehran in high radiation zone (390 to 430 cal/cm^2 - day), and Shiraz in very high radiation zone (more than 430 cal/cm^2 - day) are listed in Table 1.

Rabl and Nielsen consider the absorption of radiation as it passes through the water of a several meters deep solar pond and derive equations for the resulting temperature range of the pond during a year round operation. They take into account the heat storage in the convective layer in the bottom and in the ground underneath the pond and restrict their attention to the steady state solutions of the equations for a long run performance. With this model, the incident global (solar) flux per unit area (insolation) H(t) and the surface temeperature T(t) (taking it to be equal to the ambient temperature) both have a constant and sinusoidal term and are described by

$$H(t) = \bar{H} + \tilde{H} \cos wt \quad (3)$$

and

$$T(t) = \bar{T}_a + \tilde{T}_a \cos(wt - \delta_a) \quad (4)$$

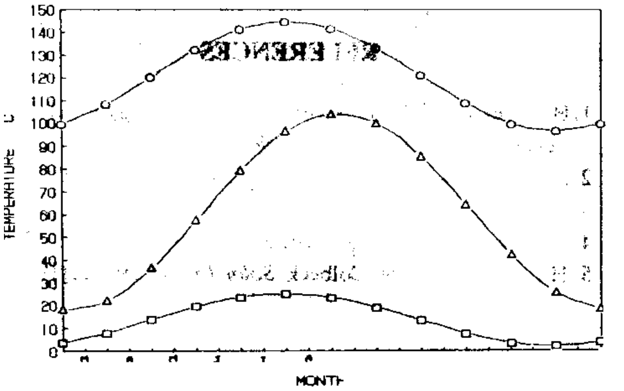

Figure 2. Temperature variation of the bottom of a pond in Mashhad with (Δ) and without (O) heat load together with the ambient temperature variation (□).

where t=0 on 21 June and the common angular frequency w corresponds to a period of 1 year. In these equations, $\bar{H}$ and $\tilde{H}$ are the average insolation and the varying part, and $\bar{T}_a$, $\tilde{T}_a$, and δ_a are the mean ambient temperature, the varying amplitude, and the phase lag with respect to insolation phase, respectively. Then, for a given rate of heat extraction from the bottom of the pond, the steady state temperature of convective layer is calculated from a radiation transition function to be also sinusoidal of the form

$$T = \bar{T} + \tilde{H} \cos(wt - \delta) \quad (5)$$

where $\bar{T}$, $\tilde{T}$ and δ are the mean temperature, the varying amplitude, and the phase lag with respect to insolation phase.

COMPUTER SIMULATION OF A SOLAR POND IN FOUR CITIES

The R.N. formulas in reference [2] are used to obtain the temperature variation at the bottom of a solar pond located in the four cities of Rasht, Mashhad, Tehran, and Shiraz in Iran. All notations are identical with the additional symbol S, defined to be the average power per square cm (load) being withdrawn from the pond. Similar simulations have been done for the southern part of Iran by Akbarzadeh and Ahmadi [4] and for London by Bryant and Colbeck [5].

The values of solar insolation for each city in Table 1 are fitted to Equation (3) to obtain the values of $\bar{H}$, and $\tilde{H}$. These values are listed in Table 2. The ambient air temperature data supplied by the Iranian Weather Institute (1951-1976 inclusive) are fitted to Equation (4) and the determined values of $\bar{T}$, $\tilde{T}$, and δ_a are also listed in Table 2.

The goal of this simulation is to calculate the mean temperature $\bar{T}$, the amplitude $\tilde{T}$, and the phase lag δ from

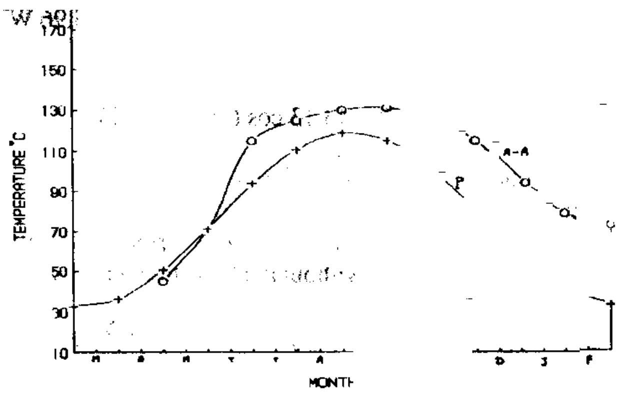

Figure 3. Comparison of the results of the present analysis (curve P) with the previous similar one (curve A-A) for a solar pond operating in Shiraz.

Equation (5) for the aformentioned four cities. For the transmission coefficient of the radiation into the pond a conservative value of 0.83 is taken. The values of the effective cos r (r= angle of reflection) are listed in Table 2. It is assumed that the pond has a sufficiently large area so that edge effect can be neglected and it is dug into soil (the thermal conductivity k=0.0096 W/cm-c, the skin depth for seasonal variations $\sigma_g = (2k_g / w)^{\frac{1}{2}}$, where k_g = the ground diffusivity). The same physical parameters as in Reference [2] are used.

RESULTS

The results for insulating layer thickness of l_i = 100 cm, various choices of convecting layer thickness, l_c, and heat load, S, are summerized in Table 3. In this table, in addition to S=0, other values of S are chosen as reasonable heat loads to heat a 200 m^2 house all year round.

Based on a value of 5.13×10^7 J/C-day (2700 Btu/F-day) to heat a house with 200 m^2 floor space, the average indoor temperature of 20°C, and the pond efficiency of 20 percent, the solar pond areas required to provide the loads are calculated to be Rasht: 117 m^2, Mashhad: 107 m^2, Tehran: 52 m^2, and Shiraz: 34 m^2, corresponding to 1679, 2372, 1168, and 912 centigrade-degree-days per year, respectively. These estimates are valid for large community ponds and obviously the performance of a finite pond would be different. More solar pond areas are required for individual house ponds in which the temperature at the bottom would be lower as the temperature near the outer edges is lower. The ratio of the average temperature of a finite pond to the temperature of an infinite pond depends on the radius in case of circular ponds, which could be as small as 0.8 [2].

As is evident from Table 3, taking Mashhad as an example, the temperature at the bottom of a solar pond with one meter of non-convecting and one meter of convecting layer thickness and an annual average load of 35.96 W/m is given by

$$T= 60.77 + 43.13 \cos (2\pi t/12-1.12) \qquad (6)$$

The pond's temperature reaches a maximum of 104°C late in July and a minimum of 18°C late in January.

The temperature variation of the bottom of this pond versus time with and without load together with the ambient temperature variation is plotted in Figure 2. It is observed that in the case of no load the temperature reaches a maximum of 145°C which exceeds the boiling point of water at normal pressure. Since this disturbs the salt gradient in the non-convecting layer, heat should be extracted from the pond at an optimum rate to prevent boiling. A fixed percent (20%) of annual mean insolation removed, which is in fact the efficiency of the solar pond, keeps the temperature of the pond reasonably below boiling point, as shown in the case with load.

To compare the results of the present simulation for the operation of a solar pond in Shiraz with the only previous similar simulation, the temperature variation of the bottom of the pond is plotted in Figure 3. Curve A-A shows the results of Reference [4] for a pond with one meter of non-convecting and zero convecting layer thickness and curve P represents the analysis for a pond with one meter of non-convecting and one meter of convecting-layer thickness operating in the same area. Both curves are plotted for 20 percent of heat removal.

It is observed that the two analyses do not compare properly. This may be due to the fact that making the convecting layer thicker reduces the seasonal variation and increases the phase lag without affecting the average temperature, as evident from Table 3.

As the presented computer simulation of the performance of solar ponds located in different solar insolations shows, it appears that solar ponds are promising as solar collectors for residential heating in most parts of Iran.

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