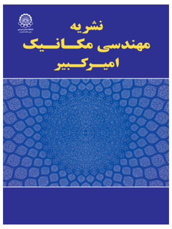

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Numerical simulation of salt gradient solar pond by employing the solar radiation estimating function considering wall-shading effects

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Abstract: In this study, a function for estimating solar radiation has been proposed using air mass effects and annual statistics of daylight conditions. A new relation for calculating the cloud cover factor has been provided by using the annual statistics of clear sky, partially cloudy, and overcast days. Estimated solar radiations have been compared with the measured experimental ones for two cities in Iran, and a good agreement has been observed. The proposed function can be used at places where the facilities and required instruments for solar radiation measurement are not available. As an illustration, the function has been used in numerical simulations of salt gradient solar ponds. One dimensional thermal analyses of the salt gradient solar ponds have been performed through an in-house code, which models the various parameters. Variation of environmental temperature, solar radiation intensity based on zenith angle of the sun, saline properties as a function of temperature and concentration, and wall-shading effects are among those parameters. A fair agreement has been observed between the results of the slat gradient solar pond numerical simulations and the experimentally measured temperatures, which shows the .capability of the proposed function for estimating the solar radiation correctly

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1- Introduction

Salt Gradient Solar Pond (SGSP) is a method of collecting solar energy in form of heat by using a pond and saline water. The collector part and the heat storage system are combined in SGSPs, which makes them economically feasible with respect to other methods [1]. Different concentrations of salt in water can be used for constructing a density gradient in pond's depth. Various parameters can affect the thermal behavior of SGSPs such as ambient temperature, Solar Radiation Intensity (SRI) at the pond's site, insulation of the pond, wall shading effects, and thickness of solar pond layers. As an illustration, there are various studies that use different functions for estimating averaged solar radiation [2]. There are also studies that calculate solar radiation through level of cloudiness of the sky. Solar radiation used in numerical simulations of SGSPs is usually taken from local weather stations. Since most weather stations are not equipped with a pyranometer, therefore, devising a function for estimating solar radiation with acceptable accuracy seems valuable. The objective of the current study is to introduce an approach for calculating Cloud Cover Factor (CCF) that is used for estimating average solar radiation. Additionally, air mass concept is used for calculating SRI in different zenith angles of the sun for a clear sky. As an illustration, the function is used for simulating SGSPs through an in-housed developed numerical code that predicts thermal behavior with a one-dimensional distribution of temperature in pond's depth direction.

2- Method Description

2- 1- Estimation of solar radiation intensity

The air mass concept indicates that when zenith angle increases, sunlight has to travel a longer distance through the air to reach the ground. It means solar radiation intensity decreases by increasing zenith angle of the sun. There are tables and functions that can calculate air mass with respect to zenith angle by assumption of flat or curved atmosphere. The SRI can be calculated by using the relation provided by researchers when the air mass and elevation of the location are known.

Generally, the effects of clouds on the SRI are taking into account by means of cloud cover factor. There are various studies suggesting different amount for CCF depend on the weather and sky conditions and geographic characteristics of the position. Although, SRI measurement requires special instruments, annual statistics of clear sky, partially cloudy, and overcast conditions are usually and easily accessible. The coefficient of 0.3 is selected for overcast days, which means SRI in an overcast day is 0.3 of SRI measured for a clear sky. Also, SRI for partially cloudy days is assumed to be mean value of SRI for the clear sky and the overcast condition.

2- 2- Thermal analysis of Salt gradient solar pond

Thermal behavior of a SGSP usually is dominated by the temperature distribution in vertical direction. Thus, it is quite common to simulate a SGSP with a one-dimensional numerical analysis [1]. Generally, a SGSP consists of three

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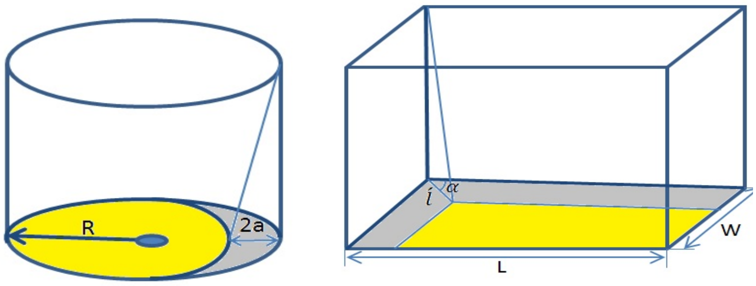

Fig. 1. Schematic of ponds with circular and rectangular cross-sections along with their shaded areas

layers; Lower Convective Zone (LCZ), Non-Convective Zone (NCZ), and Upper Convective Zone (UCZ). The LCZ and the UCZ always are assumed to have uniform temperatures due to the convection. The UCZ is directly in touch with the ambient air and therefore it is assumed to have the same temperature. Temperature distribution in NCZ varies almost linearly from UCZ to LCZ.

The ratio of shaded area with respect to the sunny parts cannot be neglected in small solar ponds. Therefore, the wall shading effects should be considered in such analyses. Two types of shapes with circular and rectangular cross-sections are quite common in the construction of small solar ponds. The schematics of the ponds with shading areas are displayed in Fig. 1. The shaded area of each one can be calculated using the relations available in the literature.

3- Results and Discussion

The method described in the previous section is applied for two cities in Iran, in which monthly averaged SRI has been measured experimentally and is available. Besides, small SGSP have been constructed in both cities and thermal behavior of them have been reported in detail [19, 20] for each month. The experiment has been carried out in the city of Bafgh in 2008 while the other one has been performed in the city of Urmia in 2016. The statistics of the weather are taken from meteorological organization for the above cities and years. Thus, CCF has been calculated and monthly averaged SRI has been derived. They compared with measured SRI reported in [3, 4]. The estimated values are in agreement with the measured data. Both comparisons are displayed in Figs. 2 and 3.

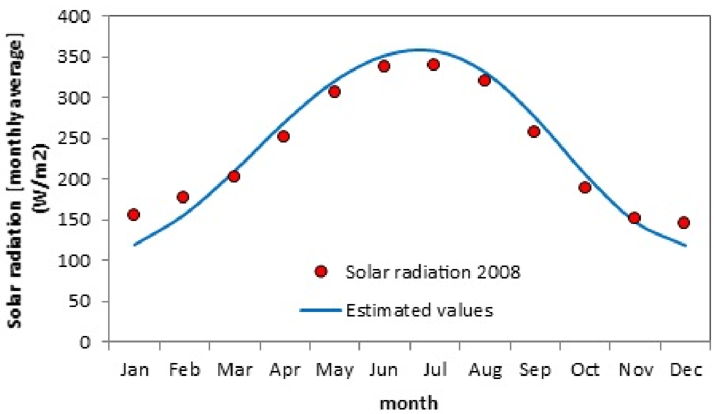

Fig. 2. estimated and measured SRI for the city of Bafgh in 2008

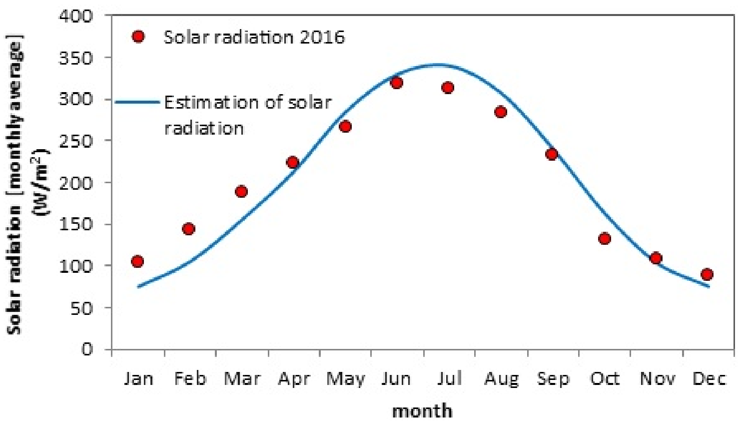

Fig. 3. estimated and measured SRI for the city of Urmia in 2016

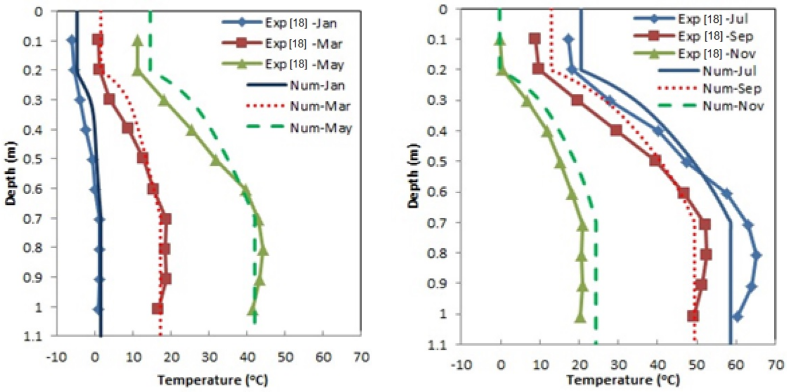

Fig. 4. Temperature distribution predicted by numerical simulation with measured data for cubic pond of Urmia

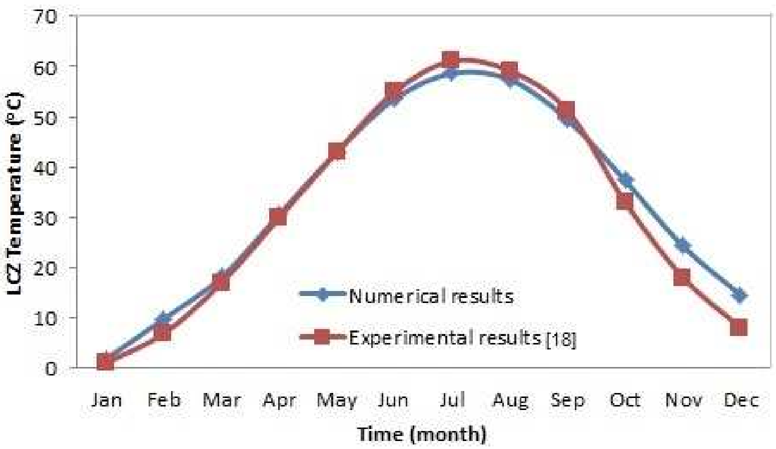

Fig. 5. Variation of LCZ temperature in a year for cubic pond of Urmia

The maximum differences between the estimated SRI with measured ones are equal to 35.2 for the city of Bafgh and 39.9 for the city of Urmia. Obviously, differences are almost 10 percent of the maximum SRI in a year for both experiments.

Temperature distribution inside the pond can be derived by using the estimated SRI for simulating SGSPs with wall shading effects and using a function for ambient temperature. As an illustration, temperature distribution resulted from the numerical simulation in comparison with the experimentally measured data for the cubic pond constructed in the city of Urmia is displayed for every two months in Fig. 4.

Fig. 5 displays variation of LCZ temperature during a year. The maximum difference occurs in December, which is about 6.5 ◦C. It seems that the in-house developed code can predict the thermal behavior of SGSPs by using the proposed function for estimating SRI.

4- Conclusions

The results showed that the relation used for calculating the cloud cover factor is accurate to predict the monthly averaged solar radiation intensity. It has been observed that the in-house developed code for simulating the SGSPs with wall shading effects predicts the experimental data accurately. The solar radiation intensity can be predicted by using the proposed function with acceptable accuracy. The relation for cloud cover factor proposed in current study seems accurate for geography of Iran. The requirements for estimating solar radiation intensity by using the proposed function is usually available everywhere and do not need special instruments or facilities. In absence of experimental measurements for solar radiation intensity, it would be difficult to predict the thermal characteristics of a SGSP. Thus, it is suggested to use the proposed function or other similar functions for predicting SRI alternatively.

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