CHAPTER IV
SOLAR RADIATION

4.1 INTRODUCTION:
The performance of the solar pond depends on the amount of solar radiation received on the surface of the pond. The solar radiation received at the pond surface is composed of direct beam and diffuse components. In general, the intensity, polarization and spectral composition of each component depends upon the zenith angle, azimuthal angle and characteristics of the area of the sky considered, as well as upon the sun angle. The radiation is received at the lower convective zone due to transparency of the pond. In (1986) Reddy T.A. et al. have analyzed the solar energy absorbed at the bottom of the pond over an entire day. John R. Hull (1982) has investigated the thermal efficiency of the solar pond with a different reflecting bottom. Viskanta R. in (1978) has presented an analysis to predict the local rate of solar energy absorption in a pond using the radiative transfer theory. The physical model considers the scattering by the water and internal reflection of radiation from the air water interface as well as the bottom. In (1984) P.D. Lund et al., have discussed the effect of pond transparency on the performance of the district solar pond using transmission spectra and extinction coefficients. In this chapter, the mean average monthly daily radiation monthly mean hourly radiation and transmissivity of water are discussed.

4.2 SOLAR RADIATION INPUT:
The amount of radiation received on the surface of the pond at any instant is obtained using latitude ($\phi$), hour angle ($\omega_h$) and sun's declination ($\delta$).

The hour angle is determined by using the equation (4.1)

$$\omega_h = \cos^{-1} \left( -\tan\phi \tan\delta \right)$$  \hspace{1cm} (4.1)

Where $\delta$ is the declination and it is given as (4.2).
\[ \delta = 23.45 \sin \left( \frac{360 \times (284 + n)}{365} \right) \]  

The latitude \( \phi \) for this pond location is 11° N. The angle of incidence \( \theta_i \) (1987) of direct sunlight varies with the time of day and year according to

\[ \cos \theta_i = \cos \phi \cos \delta \cos \left( \frac{2 \pi t_h}{24} \right) \]  

where \( t_h \) is time in hours (noon=0).

4.3 PREDICTION OF MONTHLY AVERAGE DAILY HORIZONTAL GLOBAL RADIATION:

The amount of radiation received at the surface of the pond at 11° N latitude is calculated by mean average monthly daily global radiation on a horizontal surface \( I_G \) (1993) and it is given by

\[ I_G = I_0 \left[ a + b \frac{S}{S_{\text{max}}} \right] \]  

where \( I_0 \) is the clear sky daily global radiation on a horizontal surface \( I_G \) is found by using,

\[ I_0 = \frac{24 \times 3600}{\pi} I_{\text{sc}} \left[ 1 + 0.033 \cos \left( \frac{360 \times n}{365} \right) \times [ \cos \phi \cos \delta \sin \omega_s + \frac{2}{360} \sin \phi \sin \delta ] \right] \]  

\[ S_{\text{max}} = \frac{2}{15} \cos^{-1} \left[ - \tan \phi \tan \delta \right] \]
Isc is a solar constant (W/m²), S is the monthly average actual daily sun shine duration (n) and Snm is the monthly average maximum sunshine hours (h)

4.4 HOURLY RADIATION RECEIVED AT THE SURFACE OF THE POND:

The hourly horizontal total radiation is predicted from daily horizontal total radiation. Liu and Jordan observed that long term diurnal radiation could be considered to be symmetrical about solar noon and proposed curves for the fraction of \(P\) defined as the ratio of monthly mean hourly total radiation \(I\) to the monthly mean daily total radiation \(H\) on a horizontal surface (Duffie J.A and Beckman, 1980).

\[
\bar{P} = \frac{I}{H}
\]

Collares-Pereira and Rabl (1979) proposed the following correlation,

\[
P = \frac{\pi}{24} \left( a + b \cos \omega \right) \left[ \cos \omega - \cos \omega_s \right] - \frac{\pi}{24} \sin \omega_s \left( \cos \omega_s \right)
\]

where

\[
a = 0.409 + 0.5016 \sin (\omega, -60)
\]
\[
b = 0.6609 - 0.4767 \sin(\omega, -60)
\]

and \(\omega\) is the hour angle corresponding to the mid point of the hour (in degrees).

When a ray of solar radiation is incident at angle at the air-water interface of a solar pond, part of the ray is reflected back into the air and part is transmitted into the pond at reflected angle. The refracted angle is given by Snell's law.
The reflectance is given by Fresnel's equations (Subhakar and et al., 1993):

\[
r = \frac{1}{2} \left[ \frac{\sin^2 (\theta_r - \theta_i)}{\tan^2 (\theta_r - \theta_i)} + \frac{\tan^2 (\theta_r + \theta_i)}{\sin^2 (\theta_r + \theta_i)} \right]
\]

(4.8)

The direct beam of the sun is equally divided between the two polarization and the total beam reflectance for any angle \( \theta \). Thus the radiation that crosses the pond surface is \((1-r)I_0\).

The amount of radiation absorbed by the solution according to the Beer's law is

\[
I(\lambda, x) = I(\lambda, 0) e^{-\tau(\lambda) x}
\]

(4.9)

There are many models are based on this equation to predict the radiation absorption in pure water. Rabl and Nielsen (1975) divided the solar spectrum into four zones and assign one spectral absorption coefficient for each spectrum,

\[
I(x) = I_0 \sum_{i=0}^{4} \mu_i e^{-\tau_i x}
\]

(4.10)

Bansal and Kaushik (1981) have proposed a five term model. Bryant and Colbeck have suggested and expression for water with two parameter for the transmission fraction of solar energy \( I_0 \) at depth \( x \) in water as (1977)

\[
I_0 = 0.73 - 0.08 \ln (x)
\]

(4.11)
Fig. (4.1): Monthly variation of solar energy received at the surface
Fig. (4.2): Variation of hourly mean radiation
Fig. (4.3): Theoretical and experimental variation of transmission of water with depth
An another model has been developed by Hull(1980) where transmitted solar energy as a function of depth in water is given by a three parameter equation of the following form:

\[ I_x = 0.727 - 0.056 \ln (100x) \]  \hspace{1cm} (4.12)

Equation (4.12) was obtained by dividing the solar spectrum into 40 parts.

M A Jamal and J A Muaddi (1990) have proposed the following formula for the transmission of radiation at any depth from 10 cm to 10 m and it is used in the present simulation work.

\[ \tau = 34.53 \ e^{-0.05x} \ \exp \left[ \exp \left( -2.08 \ x^{0.48} \right) \right] \]  \hspace{1cm} (4.13)

4.5 RESULTS AND DISCUSSION:

Fig (4.1) shows the monthly variation of solar energy received at the surface of pond. Fig (4.2) shows the variation of hourly mean radiation for the month of April. The transmission is tested experimentally with respect to the depth using a calibrated LDR. The LDR is immersed in the pond at different depth and radiation at each depth is recorded, the transparency of the solution is obtained from the measured value.

Fig(4.3) shows the transmission of water predicted by theoretically and experimentally. Fig shows decrease of transmission between 0.1m and 0.5m depth and deviates for other depths. M.A Jamal and J.A. Muaddi had used fresh water for their analysis, but salt water was used for this analysis. Therefore the deviation occurred.