Effect of Atmosphere Factors on Solar Energy for Iraq Marshes

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ABSTRACT

In this paper, the nature and the magnitude of effect, which caused by atmospheric constituents (Dry air molecular, water vapor, aerosols) on the transmission of solar radiation for Iraq Marshes (Al-Nasiryah Marshes (31°05 latitude and 47°17 longitude)), were studied. Its found that more less solar radiation transmittance occurred by aerosols particles, where its reduces to less than 50% at high zenith angles (> 60°).

Moreover, the study included the effect of each, the perceptible water vapor and visibility on the intensity of direct radiation as a function to zenith angle in Al-Nasiryah Marshes. Its found that each of two factors have a clear effect on the direct radiation intensity, but visibility considered as most effected factor on the direct radiation intensity.

INTRODACTION

The importance of energy represents one of the most problems that face the societies and their achievements. There are many kinds of alternatives energies can enable us in resolving some problems of energy. Because of solar energy is one of the types of the alternative energy, so we must observe the features of this energy and also we must know the changes of weather that may be influence in them before the start of carrying out the projects of solar energy. Solar radiation considers as the main energy that operates many of nature Physical and Biological Systems on the earth. On the other hand this radiation is very useful in many of man's activities in different fields like energy, agriculture, architecture engineering and weather so, the knowing of the nature and distribution of solar radiation that fall on surface earth is very important for the specialistic researchers in these fields. In addition to the systems that depend on using of solar energy require an accurate data for complete solar radiation (0–0.3) M. (*Thekaeckara, M. P., 1974*), these data enable to place along time planning for the efficiency of these systems and

this will help the researchers in this field to reduce the cost and size of these techniques and then the expansion of using these techniques in different fields of life.

In most cases, the sets of measuring the solar radiation face different problems, some of these problems are related to the operation that result from the sensitivity of some of these sets against any external effects, besides, some of these sets like the set of measuring the direct radiation depend on existence of following to the sun along day and that requires continuous observing and maintenance for these sets. The other part of problems are economical and related to high material cost for these sets, besides the material abilities that may be require for placing and operation of solar radiation stations.

As a result of these problems, the need of using mathematical patterns which becomes very urgent. These patterns calculate the components of solar radiation by using different techniques and mathematical ways. At the last time the interring with these radiation patterns greatly increases so that the most of solar radiation stations in the world becomes mainly depend on many of these patterns a specially in the field of measuring the direct solar radiation component, for examples; in USA there are (222) solar radiation stations. Use only the mathematical patterns for getting the solar radiation data. In Iraq there are (27) weather stations, six of them depend on measuring sets and the others depend on mathematical patterns.

The aim of this paper is studying the solar radiation and the most important process of attenuation which occur to this radiation during it's entrance to the atmosphere, also this paper studies the most important weather factors which effect on penetration of solar radiation.

SOLAR SPECTRUMS

The simplified picture of the sun, its physical structure, temperature and density gradients indicate that the sun, in fact, does not function as a blackbody radiator at a fixed temperature. Rather, the emitted solar radiation is the composite result of the several layers that emit and absorb radiation of various wavelengths. The photosphere is the source of most solar radiation and is essentially opaque, as the gases, of which it is composed, are strongly ionized and able to absorb and emit a continuous spectrum of radiation. In addition to the total energy in the solar spectrum (i.e., the solar constant) it is useful to know the spectral distribution of the extraterrestrial radiation, that is, the radiation that would be received in the absence of the atmosphere.

As shown in Figure (1), the maximum spectral intensity occurs at about 0.48 μm wavelength (λ) in the green portion of the visible spectrum. About 6.4 percent of the total energy is contained in ultraviolet region ($\lambda <$ 0.38 μm); another 48 percent is contained in the visible region (0.38 μm $<\lambda<$ 0.78 μm) and the remaining 45.6 percent is contained in the infrared region ($\lambda >$ 0.78 μm) (*Tiwari, G. N. and Ghosal, M. K., 2005*).

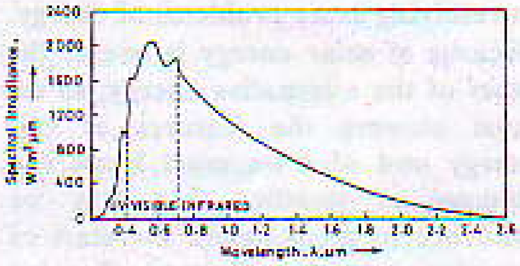


Figure 1 Spectral solar irradiance (*Thekackara, M. P., 1977*).

The solar irradiance from the black body, in the present case either sun or earth, as a function of wavelength (μm) can be governed by Planck's law of radiation given by

$$E_{\lambda b} = \frac{C_1}{\lambda^5[\exp(C_2/\lambda T)-1]} \quad \text{... ... ... (1)}$$

where $E_{\lambda b}$ represents the energy emmited per unit area per unit time per unit wavelength (μm) interval at a given wavelength, C_1 = 3.742 × 10^8 W μm^4/ m^2 (3.7405× 10^{-16} W/ m^2) and C_2 = 14387.9 μm K (0.0143879 mK).

The variation of $E_{\lambda b}$, with wavelength in μm is shown in Figure 2.

It is clear from Figures 2 (a) and (b) that the wavelength of solar radiation emitted from the sun at about 6000 K and from earth at 288 K (15°C) lies in the range of short wavelength and long wavelength range respectively as reported earlier. The comparison of these radiations from the sun and earth is shown in Figure 2 (c).

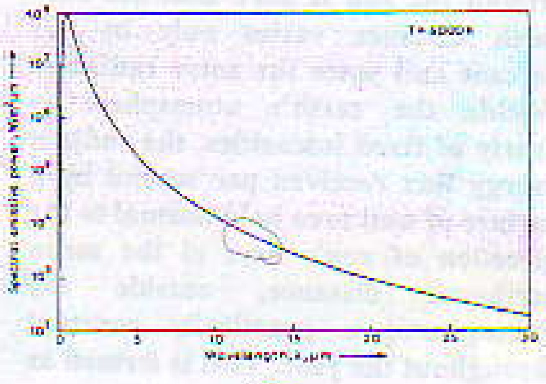
The total emitted radiation from zero to any wavelength λ from the sun can be obtained from equation (1) as

$$E_{0-\lambda,b} = \int_0^{\lambda} E_{\lambda b}\, d\lambda \quad \text{... ... ... (2)}$$

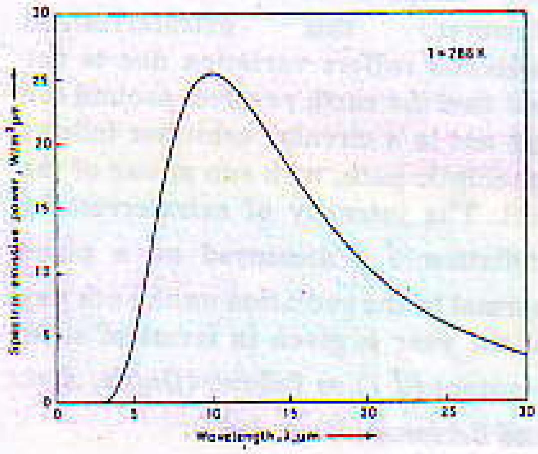
If above equation is divided by σT^4 (σ = 5.67 × 10^{-8} W/m^{2}k^4) then integral can be made to be only a function of λT as follows:

$$f_{0-\lambda T} = \frac{E_{0-\lambda T}}{\sigma T^4} = \int_0^{\lambda T} \frac{C_1 d(\lambda T)}{(\sigma T)^5[\exp(C_2/\lambda T)-1]} \quad \text{... ... ... (3)}$$

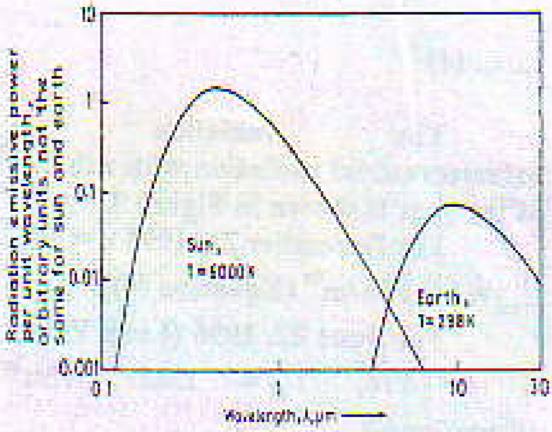
The value of $f_{0-\lambda T}$ for different λ, T, μmK, have given in the table 1 (Appendix A)



(a)



(b)



(c)

Figure 2 Effect of temperature of blackbody on emissive power
(a) T=6000K, (b) T=288K and (c) comparison.

EXTRATERRESTRIAL SOLAR RADIATION

The orientation of the earth's orbit around the sun is such that the sun-earth distance varies only by 1.7 percent and since the solar radiation outside the earth's atmosphere is nearly of fixed intensities, the radiant energy flux received per second by a surface of unit area held normal to the direction of sun's rays al the mean earth-sun distance, outside the atmosphere, is practically constant throughout the year. This is termed as the solar constant I_{sc} and its value is now adopted to be 1367 W/m². However, this extraterrestrial radiation suffers variation due to the fact that the earth revolves around the sun not in a circular orbit but follows an elliptic path, with sun at one of the foci. The intensity of extraterrestrial radiation I_{ext} measured on a plane normal to the radiation on the nth day of the year is given in terms of solar constant (I_{sc}) as follows (*Duffie, J. A. and Beckman, W. A. 1991*):

$$I_{ext} = I_{sc}\left[1.0 + 0.033\cos(360n/365)\right] \quad \ldots\ldots\ldots (4)$$

The variation of extraterrestrial radiation with *n*th day of the year is shown in Figure 3.

For December 21, 1995 n = 355.

I_{ext} = 1411 W/m² (Equation (4))

For June 22, 1996 (Leap Year), n = 174, I_{ext} = 1322 W/m² (Equation4))

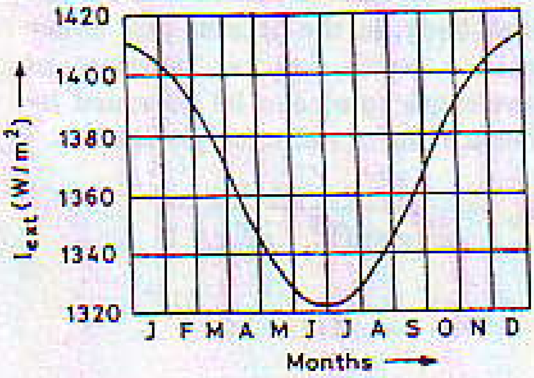


Figure 3 Variation of extraterrestrial solar radiation with time of the year

TERRESTRIAL AND EXTRATERRESTRIAL REGIONS

Solar radiations while passing through the earth's atmosphere are subjected to the mechanisms of atmospheric absorption and scattering. A fraction of the radiation reaching the earth's surface is reflected back into the atmosphere and is subjected to these atmospheric phenomenon again; the remainder is absorbed by the earth's surface. Figure 4 shows the position of terrestrial and extraterrestrial regions.

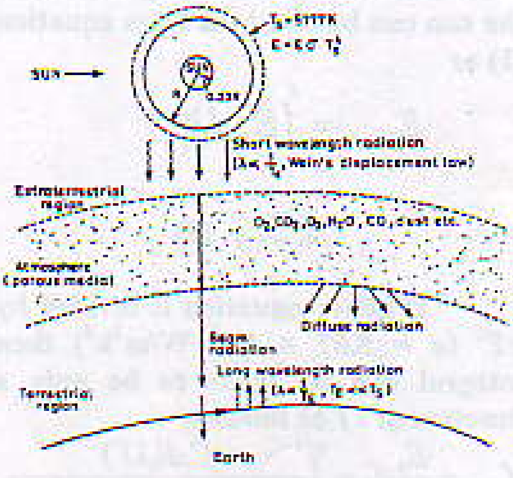
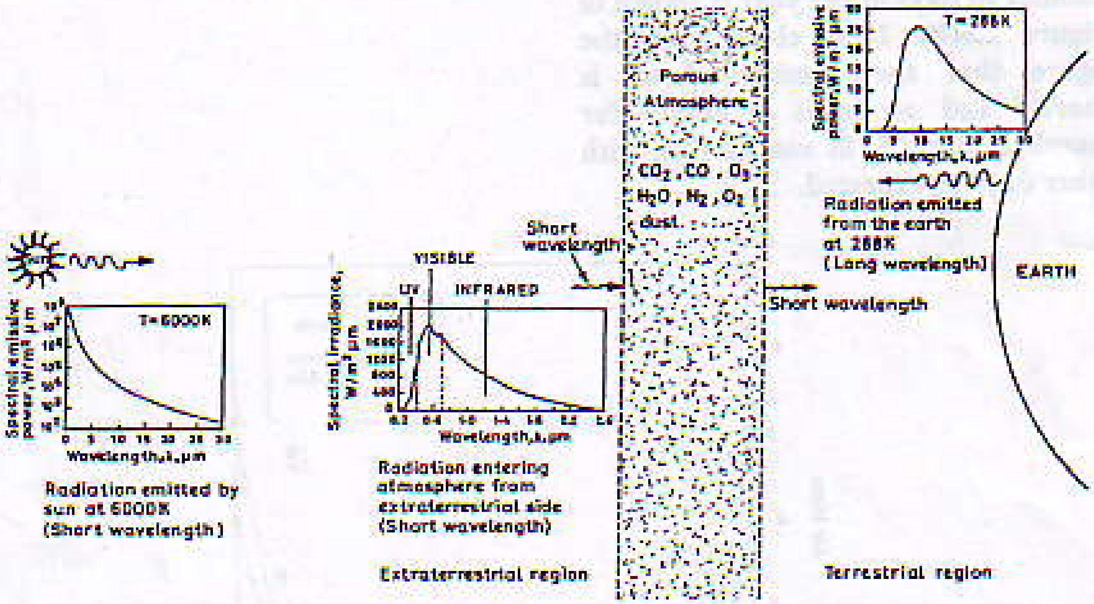


Figure 4 Position of terrestrial and extraterrestrial region.

The atmospheric absorption is due in ozone (O_3), oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2), carbon monoxide (CO) and water vapor (H_2O) and the scattering is due to air molecules, dust und water droplets. The x-rays and extreme ultra-violet radiations of the sun are absorbed highly in the ionosphere by nitrogen, oxygen and other atmospheric gases: ozone and water vapors largely absorb ultraviolet ($\lambda < 0.40$ µm) and infrared radiations ($\lambda > 2.3$ µm) respectively. There is almost complete absorption of short wave radiations ($\lambda < 0.29$ µm) in the atmosphere. Hence, the energy in wavelength radiation below 0.29 µm and above 2.3 µm, of the spectra of the solar radiation, incident on the earth's surface is negligible. Scattering by air molecules, water vapors and dust particles results in the attenuation of radiation. The range of wavelength radiation emitted from the sun, attenuation of its amplitude during propagation from the sun to atmosphere and further attenuation of radiation in the atmosphere has been shown in Figure (5) which also shows the long wavelength radiation emitted from the earth (*Tiwari, G. N. and Ghosal, M. K., 2005*).



The amount of beam solar radiation absorbed in the atmosphere is for convenience lumped into a quantity called the air mass. Figure 6(a) illustrates the concept of air mass (*Zweibel, K. 1990*). It is defined as the ratio of the mass of atmosphere through which the beam radiation passes to mass it would pass through if the sun wre at the zenith. Since the earth 's orbit around the sun is elliptical, the sun-earth distance varies over the year. This causes the air mass zero (AM0) to vary 3.4% over the year. A frequently used air mass reference condition for testing solar energy devices is AM1.5 (*Imamura M. S., et al., 1992*). Large value of air mass indicates solar radiation travel greater distance in atmosphere. Hence is prone to attenuation. An expression for air mass (referring to Figure 6(b)) is given by

$$\text{Air mass} = \frac{AB}{AC} = \cos\psi \qquad \dots\dots\dots (5)$$

At noon $\psi = 0$

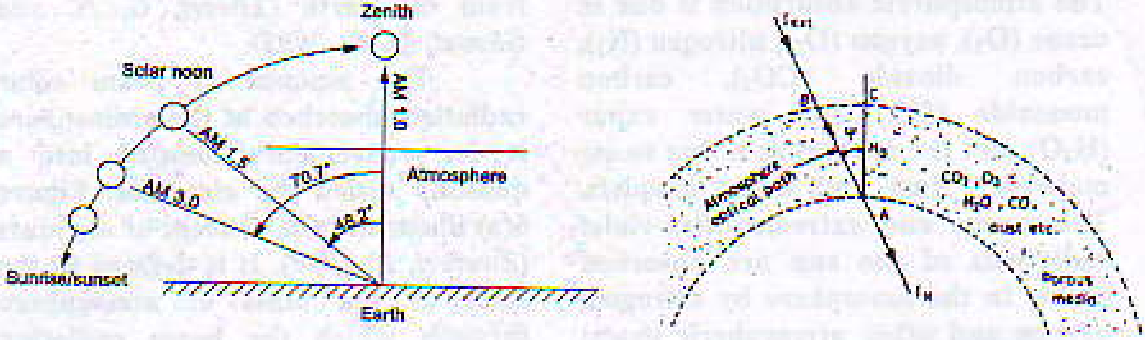


Figure 6 (a) Air mass (AM)-the path length of Figure 6 (b) Direction of sun's rays with sunlight through the atmosphere. respect to atmosphere.

The variation of air mass with time of the day for the latitude of Al-Nasiryah Marshes for different number of days of the year is shown in Figure 2.6(b). It is clear from the figure that the sunshine hour is shorter and air mass is higher for month of June 5, in comparison with other days as expected.

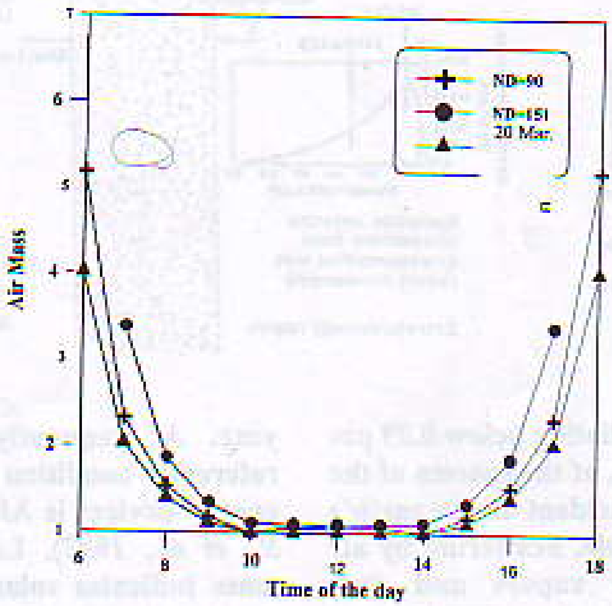


Figure 6 (b) Variations of air mass as a function of time of the days

Thus, from the view of terrestrial applications of solar energy, only radiation of wavelength between 0.29 and 2.3 μm is significant. The solar radiation, through atmosphere, reaching the earth's surface can be classified into two components, viz. beam radiation and diffuse radiation.

$$I_o = I_B + I_d \quad \text{...... (6)}$$

DIRECT SOLAR RADIATON

It is a radiation emitted directly from sun, It's have high intensity. This radiation reaches the earth surface directly from sun.

The attenuation of direct beam is the atmosphere can be presented as

$$I_D = 0.97511 I_{sc} (\cos z) \tau_r \tau_o \tau_g \tau_w \tau_a \quad \text{......... (7)}$$

The cloudless sky direct normal transmittance algorithms are essentially those given by *Bird, R. E. and Hulstrom, R. L., 1981* and *Iqbal, M. 1983*. The only exceptions are the algorithm for water vapor absorption and the algorithm for the combined effect of aerosol absorption and scattering, which were somewhat modified. All of these algorithms are broadband (solar spectrum) parameterizations and include ($\tau_r, \tau_o, \tau_g, \tau_w$ and τ_a)

The parameter I_{sc} is the extraterrestrial irradiance at the mean earth-sun distance for wavelength; $\tau_r, \tau_o, \tau_g, \tau_w$ and τ_a are the transmittance functions of the atmosphere at wavelength for molecular (Rayleigh) scattering, aerosol attenuation, water vapor absorption, ozone absorption, and uniformly mixed gas absorption, respectively .

The expression that we use for the atmospheric transmittance after Rayleigh scattering was taken from (*Bird, R. E. and Hulstrom, R. L., 1981*) and is

$$\tau_r = \exp(-0.093 (ma)^{0.84} (1 + ma - (ma)^{1.01})) \quad \text{......... (8)}$$

where ma is the pressure-corrected air mass. The relative air mass as given by (*Kasten, F., 1966*) is

$$ma = MP / P_o \quad \text{......... (9)}$$

$$M = (\cos z + 0.15 (93.885 - z)^{-1.253})^{-1} \quad \text{......... (10)}$$

where P_o = 1013 mb and P is measured surface pressure in mb.

$$\tau_o = 1 - (0.1611 U_3 (1 + 139.48 U_3)^{-0.3035} - 0.002715 U_3 (1 + 0.044 U_3 + 0.0003 U_3^2)^{-1})$$

$$\tau_g = \exp(-0.0127 (ma)^{0.26}) \quad \text{......... (12)}$$

$$\tau_w = 1 - 2.46 U_1 ((1 + 79.034 U_1)^{0.6828} + 6.385 U_1)^{-1} \quad \text{......... (13)}$$

$$\tau_a = \exp(-k_a^{0.873} (1 + k_a - k_a^{0.7088}) ma^{0.9108}) \quad \text{......... (14)}$$

$$k_a = 0.2758 k_{a\lambda}\big|_{\lambda=0.38} + 0.35 k_{a\lambda}\big|_{\lambda=0.5} \quad \text{......... (15)}$$

$$k_{a\lambda} = \beta \lambda^{-\alpha} \quad \text{......... (16)}$$

Where:

z : zenith angle

U_1 : total optical path length for the water vapor

U_3 : total optical path length for the ozone

k_a : attenuation coefficient by aerosols

β : turbidity coefficient

DIFFUSE IRRADIATION

The earth receives solar radiation not direct from sun but from cloudy or from any objects in he space. The intensity of these radiate small when comparison with direct radiate.

The diffuse irradiance on a horizontal surface is divided into three components: (1) the Rayleigh scattering component I_{dr}, (2) the aerosol scattering component I_{da}, and (3) the component that accounts for multiple reflection of irradiance between the ground and the air I_{dm}. The total scattered irradiance I_d is then given by the sum

$$I_d = I_{dr} + I_{da} + I_{dm} \qquad \dots\dots (17)$$

$$I_{dr} = 0.79 I_o (\cos z) \tau_o \tau_g \tau_w \tau_{aa} (0.5(1-\tau_r)) / (1 - ma + ma^{1.02}) \qquad \dots\dots\dots (18)$$

$$I_{da} = 0.79 I_o (\cos z) \tau_o \tau_g \tau_{aa} (F_c (1-\tau_{as}))(1 - ma + ma^{1.02}) \qquad \dots\dots\dots (19)$$

$$I_{dm} = (I_{o}(\cos z) + I_{dr} + I_{da}) r_g r_s / (1 - r_g r_s) \qquad \dots\dots\dots (20)$$

$$\tau_{aa} = 1 - (1 - w_o)(1 - ma + ma^{1.06})(1 - \tau_a) \qquad \dots\dots\dots (21)$$

$$\tau_{as} = \tau_a / \tau_{aa} \qquad \dots\dots\dots (22)$$

$$F_c = 1 - 0.5 \exp((AFS + BFS \cos z) \cos z) \qquad \dots\dots (23)$$

$$AFS = ALG(1.459 + ALG(0.1595 + ALG\,0.4129)) \qquad \dots\dots\dots (24)$$

$$BFS = ALG(0.0784 + ALG(-0.3824 - ALG\,0.5874)) \qquad \dots\dots\dots (25)$$

$$ALG = \ln(1 - (\cos\theta)) \qquad \dots\dots\dots (26)$$

RESULTS AND DISCUSSIO

The optical path length of solar radiation considers one of the most important factors which effects on penetration of solar radiation within the atmospheric, this thing is showed in (Beers Law) which gives a clear indication to the amount of attenuation that that the solar radiation is subject by components of atmosphere. This path is long relativity during the first hours of day then it starts in reducing gradually till it reaches to shorter length at midday then it increases a gain during the second part of day. We have studied the relationship between intensity of solar radiation (direct, diffuse and global) and the optical path length represented in altitude angle as showed in figures (7), (8) and (9), we notice the clear relationship between the solar radiation and the altitude angle.

For the two components of solar radiation (direct and global), we notice that increasing in intensity of solar radiation with the altitude angle is acute increasing and this matter does not appear in the component of diffuse radiation, this increasing is slow as it is showed.

The figure (10) is showing that hourly values for components of solar radiation for some choose days from March, June and September. This figure represents great interest to many weather and engineering applications and for knowing the nature of attenuation that the solar radiation is subject while its interface in the atmosphere, which result basically from diffusion and absorption that caused by air molecules and aerosols which exist in the weather. We study that the penetration of solar radiation as a function of zenith angle in marshes regions in south of Iraq,

Figure (12) shows the penetration of the solar radiation that takes place by the gases mixture (O_2, CO_2 and O_3), rayleigh and aerosols in addition to the total attenuation that occurs by the totality of these factors.

From this figure, it can be clearly observed that the effect of O_2 and CO_2 on the penetration of the solar radiation is very limited (very little). This penetration is about more than 99% for all zenith angles. As for the Ozone, it is observed that its effect is little in comparison with the effect of water vapor, rayleigh and aersols that is considered among the major factors affecting the penetration of the solar radiation. It can also be observed that the penetration of the O_2, CO_2 and O_3 doesn't change with the changes of the zenith angle and, if any, it is very slight, this can be attributed to the fact that such gases are mainly present in the higher layers of the atmosphere where the optical path length of the solar radiation is very little, there fore no clear changes of the penetration of such gases with the change of the zenith angle on the contrary of the case with water vapor and aerosols which shows clear change with the angle because of its presence in the lower layers of the atmosphere where the optical path is relatively long, and it can be noticed from the figure that the biggest attenuation that radiation suffers takes places by the aerosols of the atmosphere dust where the penetration of the solar radiation decrease to less then 50% when the zenith angle is more than 60° , as a result the effect of such molecules represent the greater part of the amount of the total attenuation that the solar radiation suffers.

Due to the fact that perceptible water vapor and visibility are considered important atmosphere factors that immediately affect on the penetration of the solar radiation. The impact of the change in that takes place in the values of such factors on the intensity of the direct solar radiation according to the zenith angle in Al-Nasiryah Marshes has been studied.

Figure (13) shows the change occurring in the intensity of solar radiation when the amount of perceptible water vapor: 0, 1, 2 and 3 respectively. According to this figure we can conclude that when the amount of water vapor is zero (i.e. when there is no absorption of water vapor) the intensity of solar radiation is as high as possible, then this intensity starts to decrease with the increase of the amount of water vapor. We can also observe that the affect of the change in the amount of water vapor is nearly the same when such amount is more than 3.

Figure (14) shows the change that takes place in the intensity of direct solar radiation when the values of visibility: 5, 10, 15 and 20 km. We can observe that there is a great effect in the visibility on the intensity of the direct solar radiation especially between 5 - 25 km and this is normal resulting from the fact that the decrease in the values of this factor is a proof of the increase in the concentration of the aerosols inside the atmosphere and as a result an increase in the diffusion and absorption of the molecules.
From the above results, it becomes clear that visibility is considered one of the most affecting atmosphere factors on the transmission of the direct solar radiation inside the atmosphere.

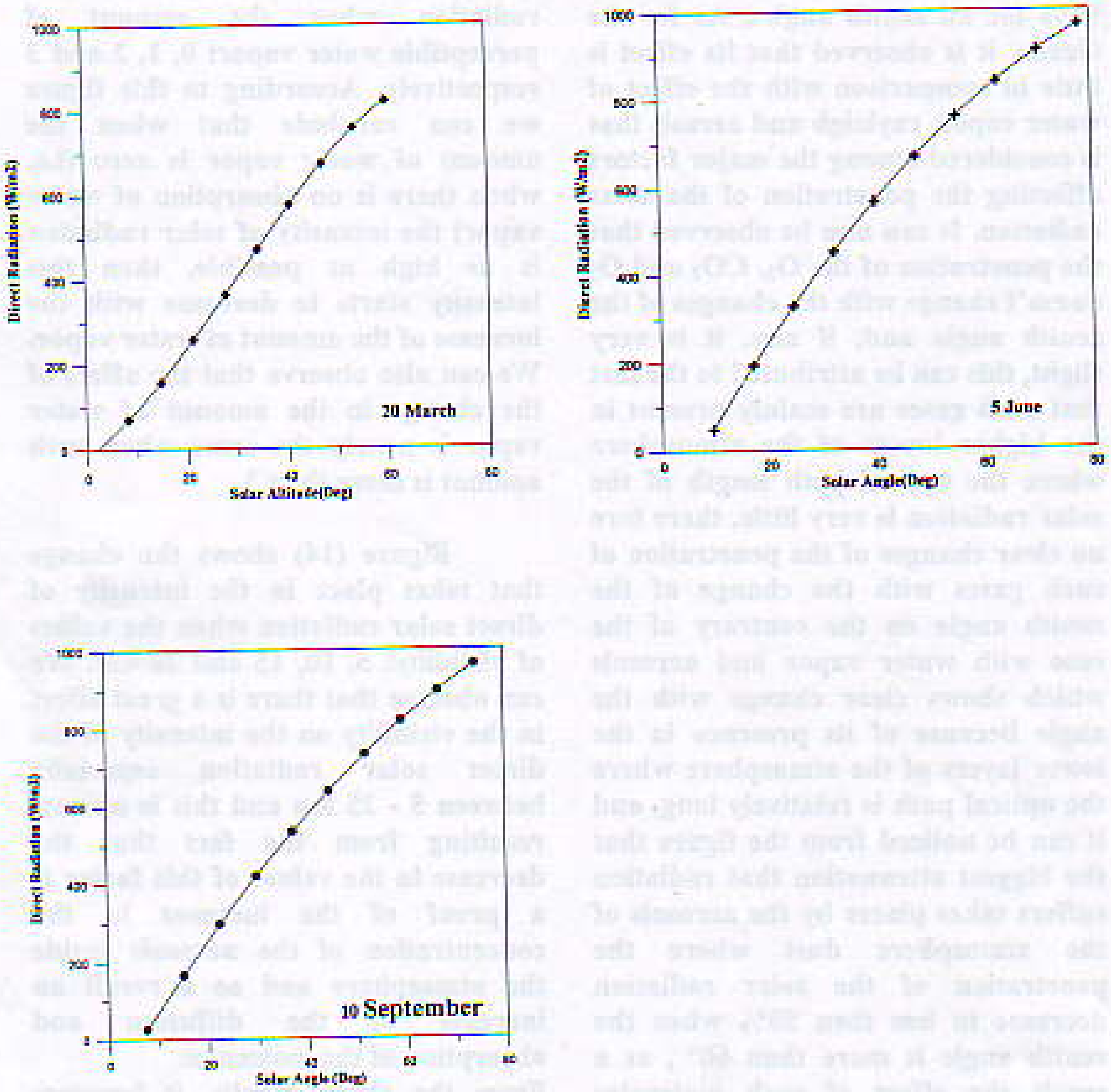


Figure (7) Relation between the direct solar radiation and solar altitude in Al-Nasiryah Marshes

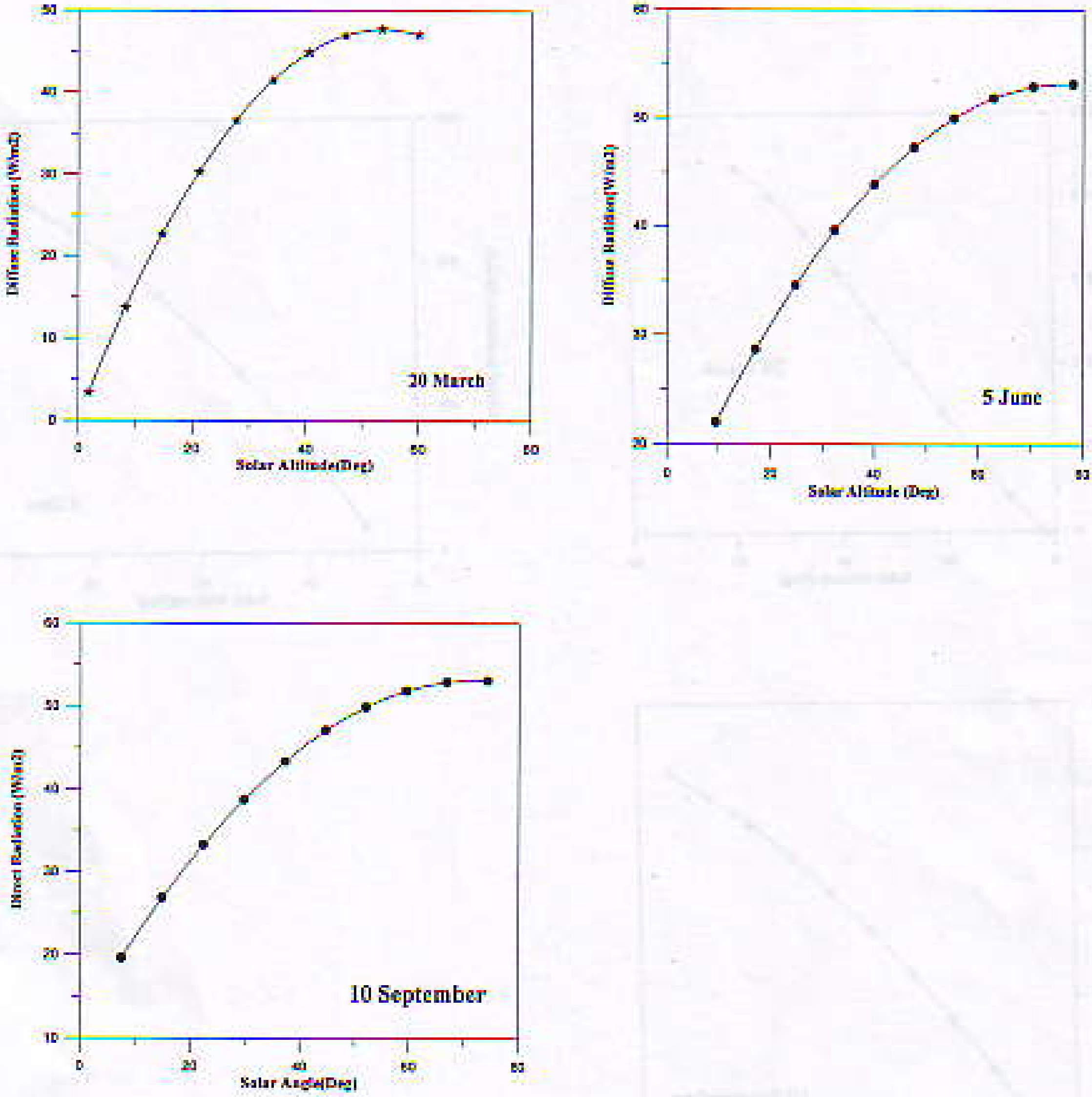


Figure (8) Relation between the diffuse solar radiation and solar altitude in Al-Nasiryah Marshes

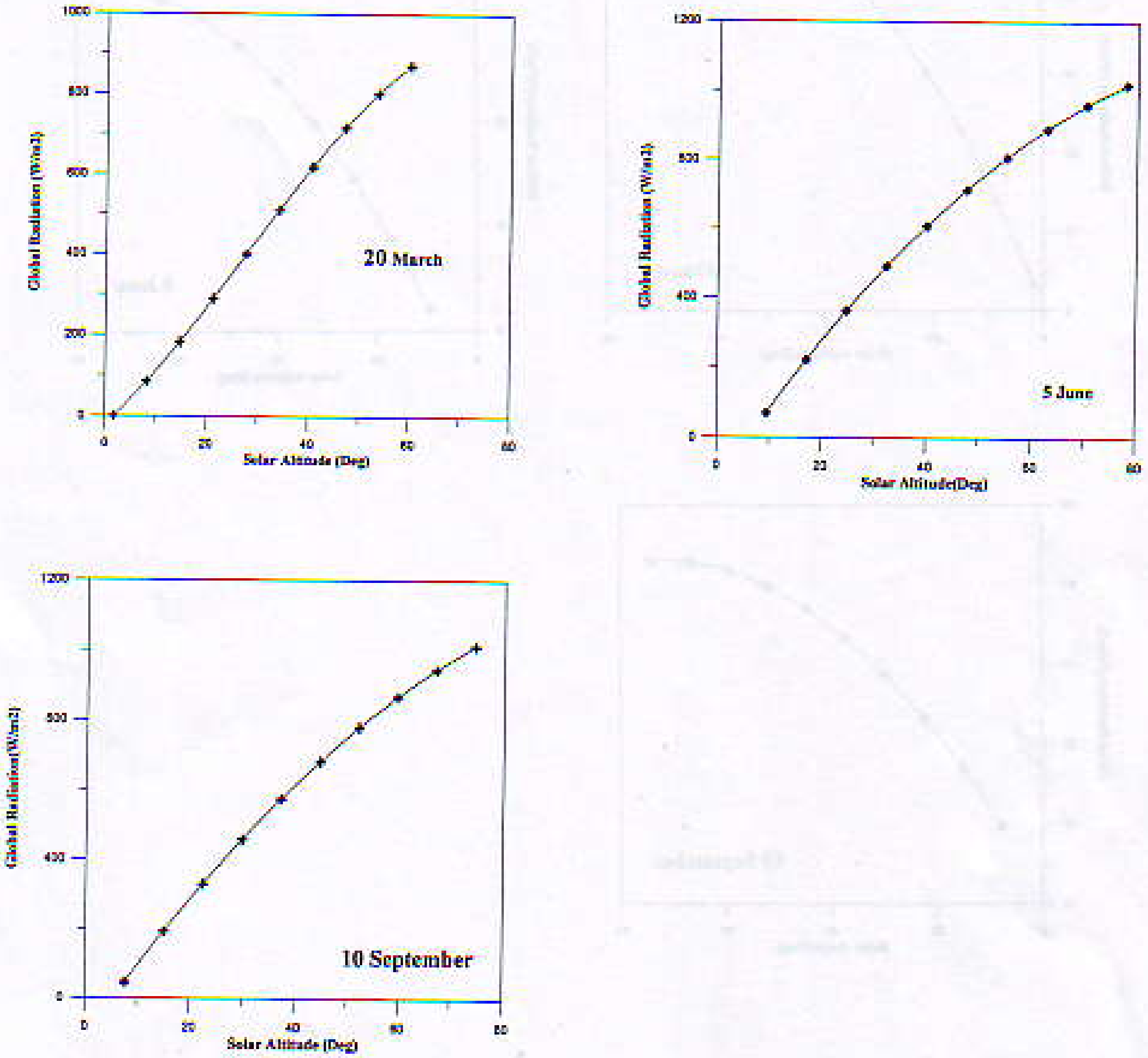


Figure (9) Relation between the global solar radiation and solar altitude in Al-Nasiryah Marshes

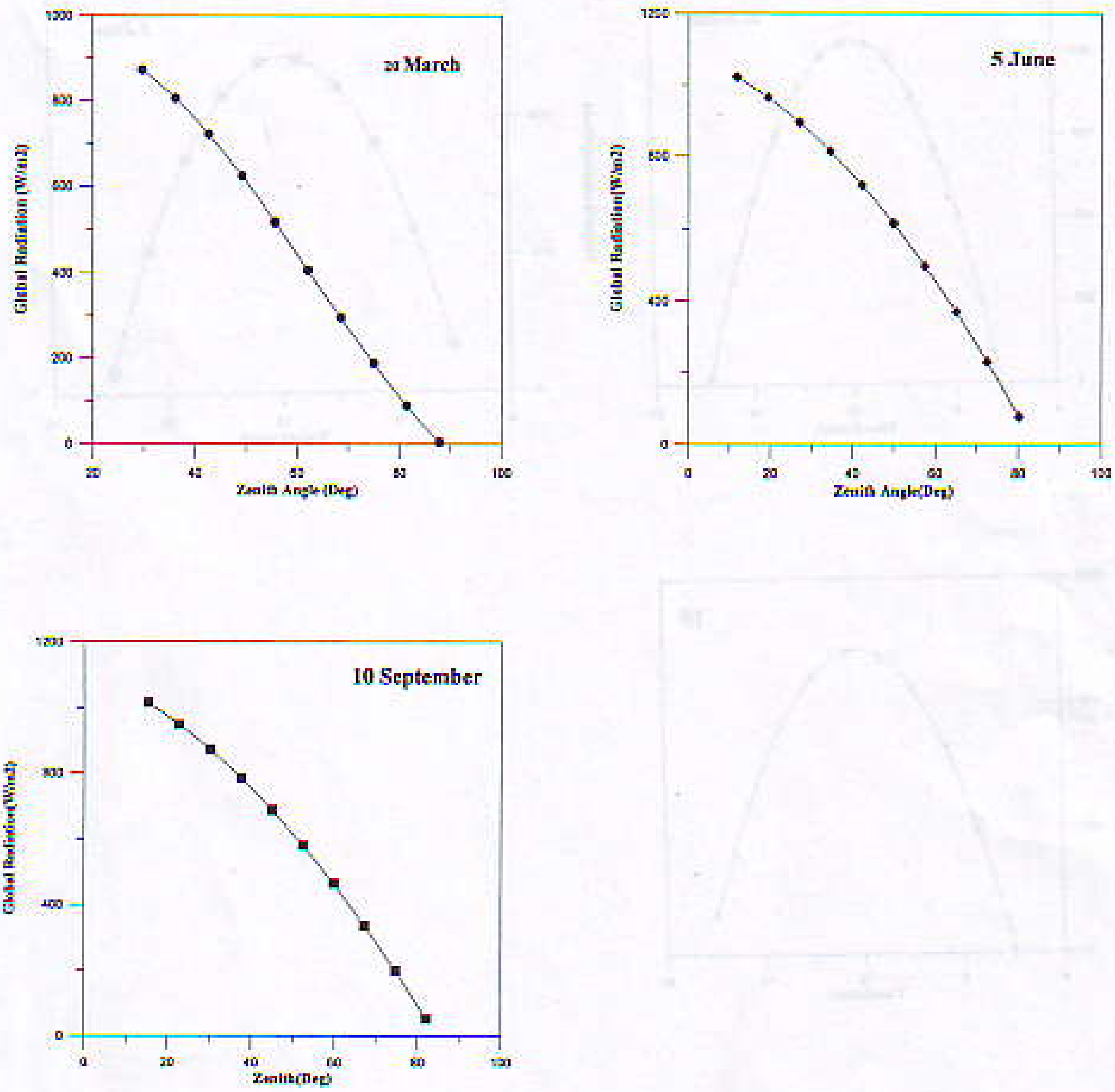


Figure (10) Relation between the global solar radiation and zenith angle
in Al-Nasiryah Marshes

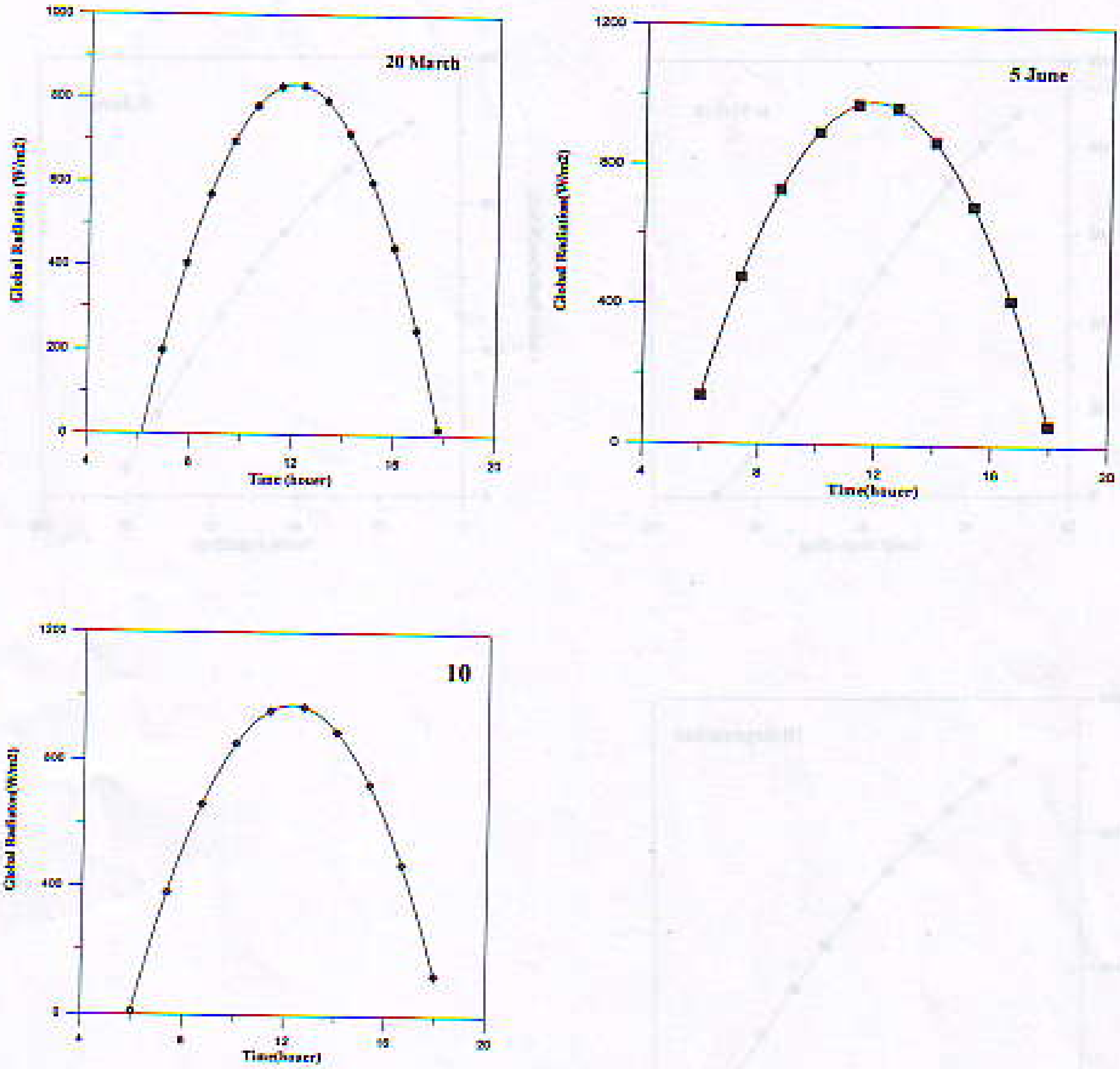


Figure (11) Hourly values for global solar radiation and zenith angle in Al-Nasiryah Marshes

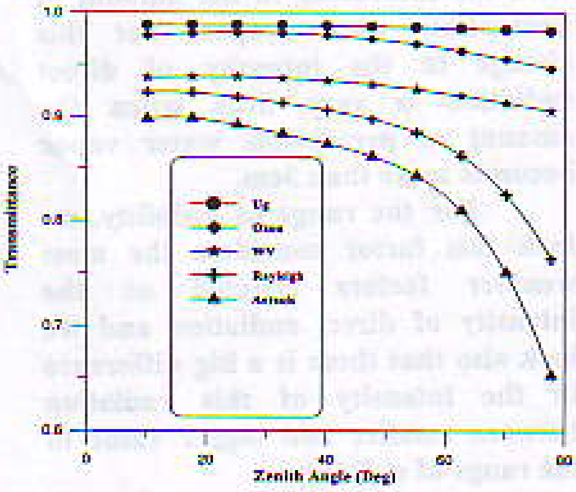


Figure (12) Transmission of the solar radiation by component of the atmosphere (Ug, Ozone, Rayleighe, Aersols) according to the zenith angle.

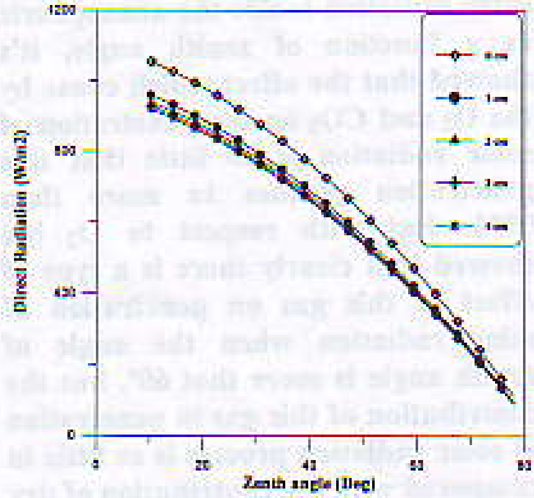


Figure (13)) The intensity of the solar radiation for different values from perceptible water vapor according to the zenith angle

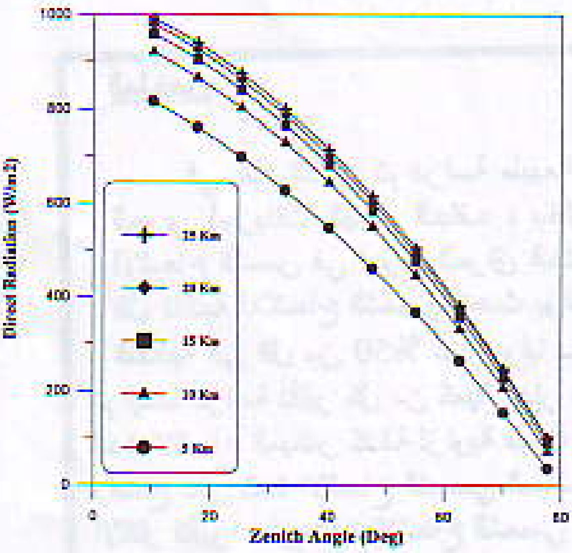


Figure (14) The intensity of the solar radiation for different values from visibility (5, 10,15, 20 and 25km) according to the zenith angle.

CONCLUSIONS

By studying the effect of weather components on penetration of solar radiation inside the atmospheric as a function of zenith angle, it's showed that the effect which cause by the O_2 and CO_2 on the penetration of solar radiation is so little that this penetration reaches to more then 99%. But with respect to O_3 it's showed that clearly there is a type of effect of this gas on penetration of solar radiation when the angle of zenith angle is more that 60°, but the contribution of this gas in penetration of solar radiation process is so little in compared with the contribution of dry air molecules, water vapor and aerosols, also its showed that the least penetration of solar radiation occurs by aerosols, this penetration is reducing to smaller than 50% at high zenith angle, therefore the penetration which occurs by aerosols represents the greatest part of total penetration amount that the solar radiation is subjected.

When we study the effect of change which occurs in values of perceptible water vapor and visibility taken as function for zenith angle on the intensity of direct radiation, there is some thing appeared, that is a clear effect in the amount of perceptible water vapor on the intensity of solar radiation, this intensity becomes fewer with the increasing in the amount of perceptible water vapor, but this change in the intensity of direct radiation is very little when the amount of perceptible water vapor becomes more than 3cm.

For the range of visibility, we look this factor considers the most weather factors effected on the intensity of direct radiation and we look also that there is a big difference in the intensity of this radiation between smaller and bigger value in the range of visibility.

الملخص

في هذا البحث تم دراسة طبيعة ومقدار التأثير الذي تسببه مكونات الغلاف الجوي (جزيئات الهواء الجاف ، بخار الماء ، دقائق الهباء الجوي) على نفاذية الاشعاع الشمس في اهوار العراق الجنوبية (اهوار مدينة الناصرية) ، وقد ظهر ان اقل نفاذية للاشعاع الشمسي تحدث بواسطة دقائق الهباء الجوي حيث تنخفض هذه النفاذية الى اقل من 50% عند زوايا سمت الرأس العالية (اكبر من 60°).
تم ايضا دراسة تأثير كل من كمية بخار الماء القابل للترسيب ومدى الرؤية الافقية على شدة الاشعاع المباشر كدالة لزاوية سمت الرأس، وقد وجد ان كلا العاملين لهما تأثير واضح على شدة الاشعاع الشمسي المباشر الا ان مدى الرؤية الافقية يعتبر العامل الجوي الاكثر تأثيراً على شدة الاشعاع الشمسي المباشر.

REFRENCES

1. Bird, R. E. and Hulstrom, R. L., (1981). "A simplified clear sky model for direct and diffuse insolution on horizontal surface". SERI/TR-642-716, Solar Energy Research Inst. Golden Co. 3-38.
2. Chameides W. L., Yu H., Liu S. C., Bergin M., Zhou X., Mearns L., Wang G., Kiang C. S., Saylor R. D., Luo C., Huang Y., Steiner A. and Giorgi F. (1999), "Case study of the effects of atmospheric aerosols and regional haze on agriculture: An opportunity to enhance crop yields in China through emission controls?" PNAS u November 23, Vol. 96, No. 24, pp. 13626–13633.

3. Duffie, J. A. and Beckman, W. A. (1991), "Solar Energy of Thermal Processes", John Wiley and Sons, New York.
4. Imamura M.S., Helm P. and Palz W. (1992), Photovoltaic System Technology- A European Handbook. H S Stephens & Associates, Bedford, UK.
5. Iqbal, asamhb6hmqMuhammad (1983). "An Introduction to Solar Radiation". Academic Press, New York, Chap. 7, 169-213.
6. Jabbar, A. (1996), "An investigation of solar pond capability in providing space heating for residential building in Baghdad", M. Sc. Thesis, University of Baghdad.
7. Kasten, F., (1966), "A New Table and Approximate Formula for Relative Optical Air Mass," Arch. Meteo. Geophs. Bioklimatol / Ser. B14, pp. 206-223.
8. Thekaeckara, M. P., (1974), "Data on incident solar energy. The energy grisis and energy from sun, Institute of environment sciences, Mt. Prospect, IL.
9. Thekaekara, M. P., (1977), Solar Irradiance, Total and Spectral, Chapter III in Solar Engineering, Edited by A. A. M. Sayigh, Academic Press, Inc. New York.
10. Tiwari, G. N. and Ghosal, M. K. (2005), "Renewable Energy Resources", Alpha Science International Ltd, Harrow, UK.
11. Zweibel K. (1990), Harnessing Solar Power – The Photovoltaic Challenge. Plenum Press, New York.

APPENDIX (A) Table (1) Value of $f_{0-\lambda T}$ for different λT (µmK) for even increment of

, µmK λT	$f_{0-\lambda T}$	, λT µmK	$f_{0-\lambda T}$	, λT µmK	$f_{0-\lambda T}$
1000	0.0003	4500	0.5643	8000	0.8562
1100	0.0009	4600	0.5793	8100	0.8601
1200	0.0021	4700	0.5937	8200	0.8639
1300	0.0043	4800	0.6075	8300	0.8676
1400	0.0077	4900	0.6209	8400	0.8711
1500	0.0128	5000	0.6337	8500	0.8745
1600	0.0197	5100	0.6461	8600	0.8778
1700	0.0285	5200	0.6579	8700	0.8810
1800	0.0393	5300	0.6693	8800	0.8841
1900	0.0521	5400	0.6803	8900	0.8871
2000	0.0667	5500	0.6909	9000	0.8899
2100	0.0830	5600	0.7010	9100	0.8927
2200	0.1009	5700	0.7107	9200	0.8954
2300	0.1200	5800	0.7201	9300	0.8980
2400	0.1402	5900	0.7291	9400	0.9005
2500	0.1613	6000	0.7378	9500	0.9030
2600	0.1831	6100	0.7461	9600	0.9054
2700	0.2053	6200	0.7451	9700	0.9076
2800	0.2279	6300	0.7618	9800	0.9099
2900	0.2506	6400	0.7692	9900	0.9120
3000	0.2730	6500	0.7763	10000	0.9141
3100	0.2958	6600	0.7831	11000	0.9318
3200	0.3181	6700	0.7897	12000	0.9450
3300	0.3401	6800	0.7961	13000	0.9550
3400	0.3617	6900	0.8022	14000	0.9628
3500	0.3829	7000	0.8080	15000	0.9689
3600	0.4036	7100	0.8137	16000	0.9737
3700	0.4238	7200	0.8191	17000	0.9776
3800	0.4434	7300	0.8244	18000	0.9807
3900	0.4624	7400	0.8295	19000	0.9833
4000	0.4829	7500	0.8343	20000	0.9855
4100	0.4987	7600	0.8390	30000	0.9952
4200	0.5160	7700	0.8436	40000	0.9978
4300	0.5327	7800	0.8479	50000	0.9988
4400	0.5488	7900	0.8521	∞	1.0000