TUDY AND APPLICATIONS ON SOLAR RADIATION

A THESIS
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BY

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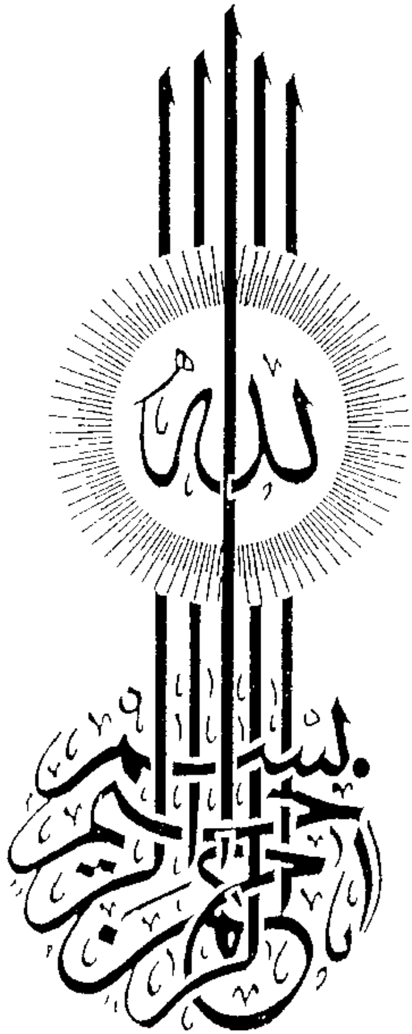
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ABSTRACT

The present thesis represents a theoretical treatment with application on the solar radiation. The study is divided into four main parts as follows :

The first part : represents a theoretical trial to predict the incident solar radiation with comparison with the corresponding meteorological measurements for different locations in EGYPT and DHAHRAN / SAUDI-ARABIA. Two empirical formulae (relations) were considered to predict the average monthly global solar radiation incident on a horizontal surface. These two relations are :

i) Angstrom correlation relation

$$\frac{\bar{H}}{H_0} = a + b\,\frac{n}{N}$$

This relation correlates the cloudiness index $\bar{H}/H_0$ (the clearliness index) and the fraction n/N of maximum possible number of hours of bright sunshine (relative duration of sunshine). Where, "$\bar{H}$" is the monthly average of the daily global solar irradiance on a horizontal surface, "H_0" is the extraterrestrial solar irradiance. "n" is the monthly average of daily hours of sunshine, "N" is the maximum daily hours of sunshine and, a and b are regression constants.

ii) Barbaro correlation relation which requires only hours of sunshine and minimum air mass as input parameters and is written in

the form :

$$H_m = K\ (n_m)^{1.24}\ \alpha^{-0.19} + 10550\ (\sin \alpha)^{2.1} + 300\ (\sin \alpha)^3$$

where H_m and n_m are the monthly global irradiance and the monthly sunshine hours respectively. α is the noon altitude of the sun on the 15th of the month while K is a zone parameter.

These two methods are applied to five zones in EGYPT which are ASWAN, ASYUOT, BAHTIM, EL-TAHRIR and CAIRO, as well as applied DHAHRAN region in Saudi Arabia. The parameters in each of the considered relations are determined and comparison is made between the measured and computed values of the monthly average of the daily global solar radiation $\overline{H}$ on a horizontal surface for the considered regions.

The second part : represent a solution of the heat diffusion equation for a flat plate collector. Its efficiency is also evaluated. Such a study required the determination of the function q(t), that predicts the hourly daily global solar radiation incident on a horizontal unit area of the surface of the flat plate absorber per unit time. The function q(t) is predicted and comparison between the measured and computed values. Such a comparison is made for different cities in different countries. These cities are Hong Kong, Barcelona, Jeddah, Cairo (AL-AHRAM region), where satisfactory fitting is obtained. Solving the heat diffusion equation makes it possible to find the temperature θ(t) of the absorber of a flat plate absorber. The function θ(t) shows the variation of the absorber temperature θ as a function of the hourly local time along the day.

The study shows the function dependence of $\theta(t)$ on the physical parameters of the absorber, and its dependence on $q(t)$ from sunrise up to sunset is also revealed.

The third part : deals with a study of the efficiency of a flat plate collector for different values of the heat transfer coefficient at the side where the working fluid flows.

Such an efficiency is obtained in terms of the previously obtained functions $q(t)$ and $\theta(t)$. Three metallic absorbers are considered, namely Aluminum, Copper and Stainless Steel.

The fourth part : concerns the calculation of the temperature of the working fluid, outcoming from the solar flat plate collector, for two considered special cases :

i) In the first case it is suggested that water as working fluid when scanning the absorber rear surface receives a part of the heat gained by the absorber during the considered interval of time.

ii) In the second case it is suggested that the absorber does not give all the heat energy gained during the exposure time; thus its temperature raises gradually.

The study of the efficiency for both cases revealed that Stainless Steel is a more efficient surface compared with the other two metals Aluminum and Copper. The main factor limiting this recommendation is the difficulty with which Stainless Steel is shaped. Thus, the metal processing techniques and facilities are also important to decide which metal to be used as an absorber in a flat plate collector when other operating conditions and the calculated efficiency are the same.

CHAPTER (1)

INTRODUCTION

1.1 Sun Model

The sun is the ultimate origin of most of the energy presently available on earth. This includes the energy for direct heating, as well as wind energy, hydroelectric power, and energy derived from fossil fuels. Fossil fuels exist today as a consequence of photosynthesis, the process through which plants convert solar energy to chemical energy. A complete understanding of solar energy technology is only possible with a through analysis of solar radiation.

The sun, our closest star, provides the energy to maintain life on earth and produces the necessary gravitational attraction to keep our planet in a nearly circular orbit. It has a mass $M \simeq 1.99 \times 10^{30}$ Kg ($\approx 3.3 \times 10^{5}$ earth mass) and a radius of $R = 6.96 \times 10^{8}$ m ($\approx$ 109 earth's radius), the earth-sun distance varies from 1.0167 AU (aphelion, $\sim$ July 4) to 0.983 AU (perihelion, $\sim$ January 4) and has an average value of 1 Au (1 AV= 1 astronomical unit $\simeq 1.5 \times 10^{11}$ m).

The interior of the sun is inaccessible to us for direct experimentation. However, based on observations of the solar surface and theoretical considerations, it is believed that the interior temperature is about 15 million kelvins. The chemical composition of the sun is mainly hydrogen with a lesser amount of helium. These two elements, which account for 96 to 99 percent of the sun's mass, are under enormous pressure and only the large gravitational pull of the sun keeps this mass together. Energy is generated in the interior through the nuclear fusion of hydrogen into helium. This energy finds its way to the surface and is eventually emitted into space primarily in the form of electro-magnetic radiation. The surface of the sun, the photosphere, is actually a transition region in which the density falls off rapidly. As we move from the interior of the sun to the outer part of the photosphere, we pass from an optically opaque medium to a relatively transparent one. Furthermore, the temperature falls to approximately 6000 K. Above the photosphere is the sun's atmosphere, which is called the chromosphere because it selectively absorb certain colours of the radiation emitted from the photosphere. Because it is relatively transparent, we will ignore its effects on the emitted solar radiation. Most of the radiation reaching us emanates from the photosphere so that the solar spectrum is determined by the optical and thermal properties of the solar surface.

The simple model being used here assumes that the sun behave as a black body whose surface is maintained at T=6000 K. This surface temperature is kept constant by a source of energy located in the interior. As a result of this elevated temperature, the surface glows and electromagnetic radiation is emitted in all directions of space (Figure 1.1).

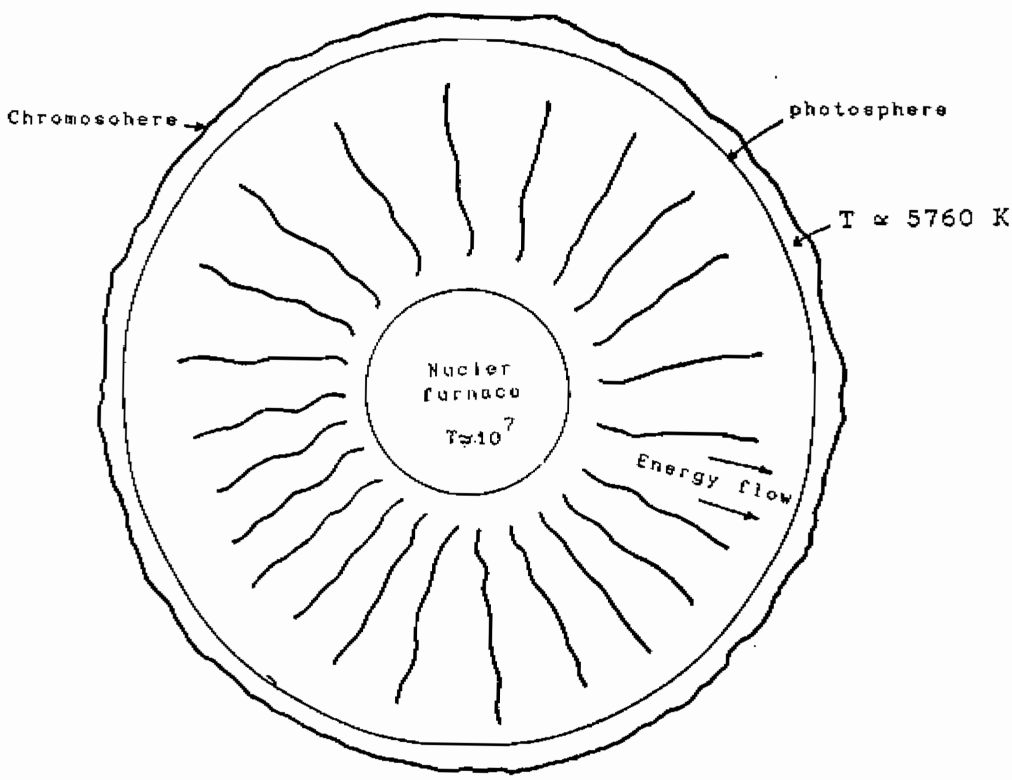

Fig. (1.1) A simplified model of the sun.

1.2 Radiation Emission from the Sun

If we take the model of the sun to be a black body at a steady-state temperature T, then the radiant flux emitted at the solar surface can be represented by a Planck distribution. A good approximation to the solar spectrum is a black body curve corresponding to a temperature of $T \simeq 5800$ K, as can be seen from (Figure 1.2).

The characteristic wavelength of the solar spectrum is :

$$\lambda_{max} = \frac{2.9 \times 10^{3}\ \mu\text{m-K}}{5800\ \text{K}} = 0.500\ \mu\text{m} = 500\ \text{nm},$$

which corresponds to green light.

The total flux leaving the surface of the sun :

$$F = \sigma\ T^{4} = \left(\frac{5.670 \times 10^{-8}\ \omega}{m^{2} - K^{4}}\right)(5800\ \text{K})^{4} = 6.416 \times 10^{7}\ \text{W/m}^{2}.$$

This radiation is diffuse (traveling in all directions) when it leaves the solar surface.

The total radiant power emitted from the sun is obtained by multiplying the flux above by the surface area of the sun. Then :

$$P = F 4\pi R^{2}.$$

$$P = (6.416 \times 10^{7}\ \text{W/m}^{2})\ (4\pi)\ (6.96 \times 10^{8}\ \text{m})^{2}.$$

$$P = (3.91 \times 10^{26})\ \text{W}.$$

If the sun emits radiation isotropically, this enormous power, called luminosity by astronomers, is emitted equally in all directions of space.

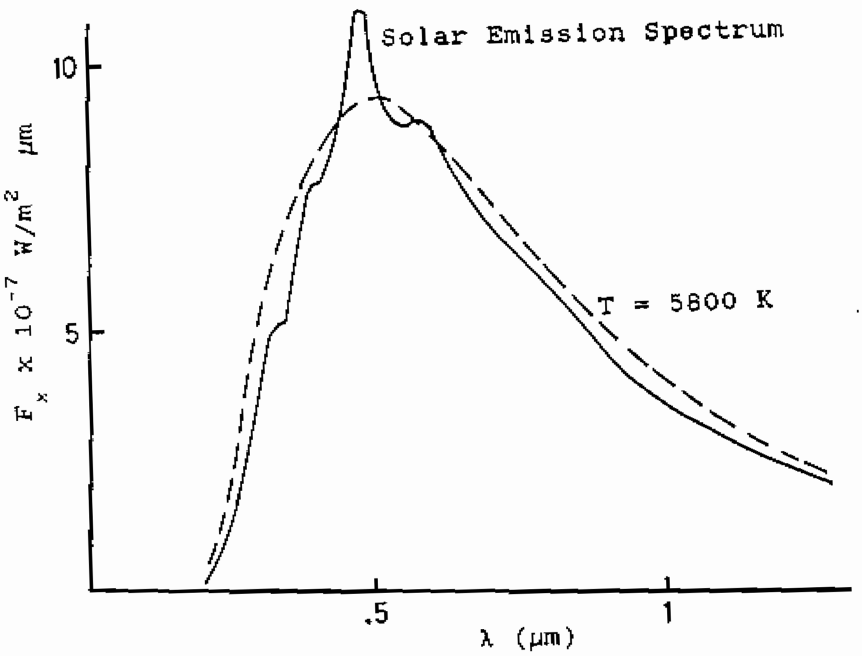

FIG.(1.2) The spectral distribution of the flux emitted from the sun's surface. The dashed line is the emission spectrum of a black body at 5800 K.

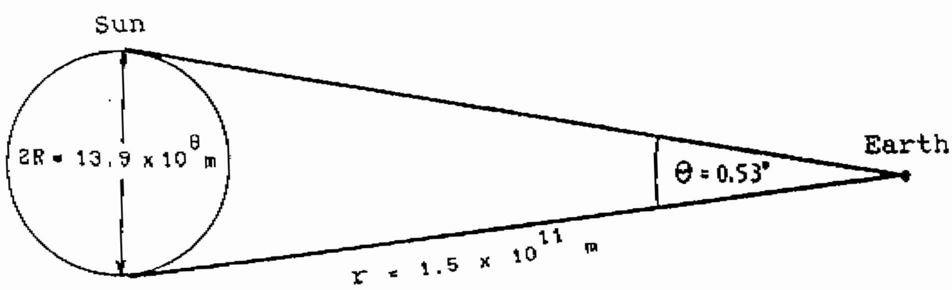

FIG.(1.3) The geometry for determining the divergence angle of the solar constant .