SOLAR CROP DRYING

Gordon Yaciuk, in Solar Energy Conversion II, 1981

Design of the Heat Source

If measurement of solar radiation is possible with suitable instrumentation this section would be only of minor importance.

The method to calculate direct solar radiation is that used by Yaciuk (1973). It It is a relatively simple method which lends itself to computer calculations in determining heat transfer rates using finite difference techniques, and has been found adequate in simulating temperatures in grain storage systems (Yaciuk, Muir and Sinha, 1975).

1. Solar altitude and solar zenith angles. The angle the sun makes with the horizon is known as the solar altitude (the intensity of the solar radiation received on earth's horizontal surface is directly proportional to the sine of the solar altitude.

   Solar altitude is a function of latitude (ϕ), hour of day (h), and declination angle (δ). The declination angle is the angular distance of the sun north (–) or south (–) of the celestial equator. The zenith angle (ζ) is equal to π/2 radians–the altitude angle and is given by: (Threkeld, 1970)

   (19)

   $$\zeta = \cos^{-1}\left(\sin\phi\sin\delta + \cos\delta\cos\, h\right)$$

2. Azimuth angle. The sun's azimuth angle (the angle in the horizontal plane measured from north to the horizontal projection of the sun's rays) is given by:

   (20)

   $$\gamma = \sin^{-1}\left(\cos\delta\sin\, h/\sin\zeta\right)$$

   The latitude of several locations in the world can be obtained from the ASHRAE guide (ASHRAE, 1972).

3. Hour of sunset. Since the earth rotates on its axis every 24h then each degree of rotation represents a time of 4 min. At solar noon h = 0 and ζ = ϕ – δ. Then at sunset ζ = π/2. Therefore, from equation (19) the solar hour angle at sunset is:

   (21)

   $$\mathrm{H}^{+} = \cos^{-1}\left(-\tan\phi\tan\delta\right)$$

   Since the solar hour angle is symmetrical about solar noon, the sunrise solar angle (H^-) would be $-H^+$. For latitudes greater than 66.5°N the possibility of a day or night longer than 24 hours exists. Equation (21) can only be applied when |ϕ| <π/2 – δ since $\cos^{-1}$ |tan ϕ tan δ|>1 is undefined.

4. Radius Vector. The radius vector is the ratio of the distance from the centre of the earth to the sun to the length of the semi-major axis of the earth's surface

and can be calculated by (McCullough and Porter, 1971)

$$R \approx \{1/(1 + 0\cdot 0335 \cos(2\pi\chi/365))\} \tag{22}$$

where χ = the day of the year.

The radius vector can be assumed constant for any one day.

5. Declination angle. McCullough and Porter (1971) suggest the following equation to calculate the declination angle:

$$\delta \approx \sin^{-1}[0\cdot 3978 \sin\{2\pi/365(x - 80) + 0\cdot 0335(\sin 2\pi\chi/365 - \sin 160\pi/365)\}] \tag{23}$$

Alternatively δ can be calculated in degrees from: (Lokmanhekim, 1971)

$$\delta = 0\cdot 302 - 22\cdot 93\cos(w'\chi) - 0\cdot 229\cos(2w'\chi) - 0\cdot 243\cos(3w'\chi) + 3\cdot 851\sin(w'\chi) + 0\cdot 002\sin(2w'\chi) - 0\cdot 055\sin(3w'\chi) \tag{24}$$

where $w' = 2\pi/366$

The declination angle can be assumed equal throughout one day.

6. Albedo. Albedo is the percentage of short-wave radiation incident on the earth's surface that is reflected by the earth's surface. Albedo (a_ℓ) can be approximated by (Brunt, 1939):

$$a_{\mathscr{L}} = 0\cdot 70C_C + 0\cdot 17(100 - C_C) \tag{25}$$

where C_c = cloud cover, per cent.

7. Instantaneous flux at outer atmosphere. The instantaneous flux of solar radiation at the top of the atmosphere is:

$$I_0 = \frac{S}{R^2}\cos\zeta \tag{26}$$

where I_o = heat flux at top of atmosphere

S = solar constant

An exact solution is available for integration of equation (26)

8. Instantaneous flux at the earth's surface. Kreith (1969) suggests that the instantaneous flux at the earth's surface is:

$$I_e = \frac{S}{R^2}\cos\zeta(1 - a_{\mathscr{L}})^{\sec\zeta} \tag{27}$$

where I_e = heat flux at earth's surface

9. Instantaneous flux on a tilted surface. For a surface tilted ψ degrees from the horizontal and whose normal faces ∝ degrees westward, the radiation intensity can be divided into perpendicular and parallel components (Kreith, 1969). The ratio of the intensity incident on the tilted surface (I_v) to the intensity incident on a horizontal surface (I_e) is given by:

$$I_V/I_e = \cos|\zeta - \psi| - \sin\zeta \sin\psi + \sin\zeta \sin\psi \cos|\gamma - \propto| \quad (28)$$

where I_v = heat flux on surface tilted ψ degrees from the horizontal.

Thus, equation (28) becomes:

$$I_V = I_e\,(\cos|\zeta - \psi| - \sin\zeta \sin\psi + \sin\zeta \sin\psi \cos|\gamma - \propto|) \quad (29)$$

To the best of my knowledge, no exact solutions exist for equation (27) or equation (28). Integration using the trapazoidal rule with increments of four minutes (one degree) has been found satisfactory (Yaciuk, 1973).

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