Introduction to Solar Energy

The Nature of Solar and Atmospheric Radiation

Solar radiation that is useful for applications is the thermal electromagnetic radiation from the incandescent surface of the sun falling on solar collectors at the surface of the Earth. It consists mainly of ultra-violet light, visible light, and near infra-red radiation. Besides solar radiation, there is also **atmospheric radiation**, which is the thermal radiation emitted by the atmosphere in the far infra-red region of the electromagnetic spectrum.

Because of the relationship between the wavelengths of visible light and infra-red radiation, solar radiation is often called **short-wave radiation**, and atmospheric radiation is often called **long-wave radiation**. Solar radiation has wavelengths mainly between 0.3 μm and 3 μm; atmospheric radiation has wavelengths mainly between 5 μm and 50 μm. It is of great practical importance that these two wavelength ranges do not overlap (Fig. 1).

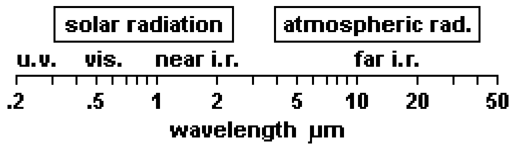

Fig. 1. Solar and atmospheric radiation in the electromagnetic spectrum. u.v. = ultra-violet, vis. = visible, i.r. = infra-red.

In addition to solar radiation and atmospheric radiation from the sky, a solar collector may receive radiation from objects on the ground if the collecting area is exposed to them. This will contain long-wave radiation emitted by the object itself, and short-wave radiation if sunlight is reflected from the object. Such radiation is difficult to calculate theoretically; we shall ignore it because it is not usually important in practice.

The solar radiation reaching the surface of the earth may be divided into two components: **beam solar radiation** coming directly from the sun's disk, and **diffuse solar radiation** coming from the whole of the sky except the sun's disk (Fig. 2). It is the beam solar radiation that throws sharp shadows and can be focused by optical systems. Diffuse solar radiation does not throw sharp shadows and cannot be focused.

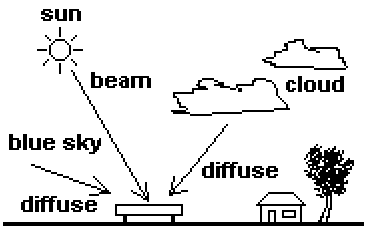

Fig. 2. Beam and diffuse solar radiation.

Radiation fluxes are given in terms of the quantity of radiant energy flowing through unit area of a surface in unit time. The standard measure of beam solar radiation is the flux from the sun's disk falling on a surface perpendicular to the solar beam; this is called **beam solar irradiance**. In bright sunlight its value is about 0.9 kW/m^2. The standard measure of diffuse solar radiation is the diffuse short-wave flux falling on a horizontal surface facing upwards; this is called **diffuse solar irradiance**. Its value depends on weather conditions. Under a clear sky it is typically 0.1 kW/m^2, but under cloudy conditions it may vary from 0.3 kW/m^2 to 0.6 kW/m^2.

The sum of beam and diffuse solar irradiance falling on a horizontal surface facing upwards is called **global solar irradiance**. If I_b is the beam solar irradiance, ζ is the angle of incidence of the solar beam on the horizontal surface, and I_d is the diffuse solar irradiance, then the global solar irradiance I_g is given by

$$I_g = I_b \cos \zeta + I_d.$$

In the case of atmospheric radiation all the radiation is diffuse, so there is only one standard measure of it: the long-wave radiation flux falling on a horizontal surface facing upwards. This is called **downward atmospheric irradiance**. Its value depends mainly on the temperature of the air near the Earth's surface, and on the amount and height of the clouds in the sky. Usually downward atmospheric irradiance is equal to the irradiance of a blackbody at a temperature a few degrees Celsius less than the temperature of the air near the surface of the Earth. In the temperature range 10 °C to 30 °C the downward atmospheric irradiance may typically be in the range 300 W/m^2 to 450 W/m^2.

The sum of the short-wave and long-wave radiation fluxes incident on a horizontal surface facing upwards is called the **total**

downward irradiance. If I_a is the downward atmospheric irradiance, then the total downward irradiance is $I_g + I_a$.

The Main Uses of Solar Energy

The main uses for which solar energy has potential are:

- Water Heating
- House Heating
- Agricultural Crop Drying
- Electricity Generation using Photovoltaic Cells
- Thermal Electric Power Generation

Water heating to moderate temperatures may be used for homes, hospitals, small industries, etc. **Flat plate collectors** are suitable for most of these applications. A flat plate collector consists of:

- a black metal plate for absorbing solar energy
- a number of tubes attached to the black plate to carry the water
- thermal insulation behind the black plate and the tubes
- a box with a transparent cover.

The transparent cover of glass or plastic allows short-wave (solar) radiation to enter the box and fall on the black plate, but it prevents the long-wave (thermal) radiation emitted by the black plate from being lost. Collectors of this type can produce water temperatures in the range from ambient temperature (20°C to 40°C in hot countries) to the boiling point of water (100°C), depending on the design and the operating conditions.

Another kind of collector that can be used for water heating is the **evacuated tube collector**. The collector contains an array of evacuated glass tubes. Each tube contains a long thin black absorber plate thermally attached to a pipe inside the glass tube. The vacuum inside the tube prevents heat loss, and water temperatures up to 100°C can be reached. The hot water can be used for industrial processes.

Concentrating collectors have large mirror systems to focus beam solar radiation onto a pipe containing water (or other liquid) or onto a small receiver. The mirrors must be moved mechanically to follow the movement of the sun throughout the day. These collectors produce higher temperatures than flat plate collectors, but they are more expensive and more difficult to use. Small concentrating collectors may be used in bright sunlight for cooking food when other fuel is scarce.

House heating may be **passive heating** or **active heating**. Passive heating and cooling is achieved by designing the house to let in the solar radiation during the winter and keep out the solar radiation in summer. Active heating systems use fans and solar collectors to heat the air and move it around the house. A bed of rocks under the house may be used to store the heat. Such systems can also cool the house at night, and make the bed of rocks cool for later use during the day.

Agricultural crop drying is usually a good use for solar radiation. Solar heated air is not so hot that it spoils the produce, and the drying system protects food crops from rain, dirt, and insects. The use of solar heat for timber seasoning can save large amounts of conventional energy.

Photovoltaic (PV) cells convert sunlight directly into electricity. This electricity can be stored in batteries for later use, especially for small scale applications such as: lighting, other home uses (fans, radio and TV, refrigerators, etc.), pumping drinking water from wells, operating remote communications relays, etc.

Various systems can be used for the **large scale generation of electricity**, such as:

- Large arrays of concentrating collectors to generate steam.
- Central power towers into which a large field of movable mirrors concentrates solar radiation to produce very high temperatures.
- Large fields of photovoltaic cells.

Thermal solar systems cannot compete economically against conventional power generation methods, but photovoltaic arrays are becoming more important and will make significant contributions to electric power generation in the future.

By R. H. B. Exell, 2000 (revised 2018). JGSEE, KMUTT.
