18ME651
Non-conventional Energy Sources

IAT 2

Answer all questions.

1) With relevant figures define the following: [20 marks]
   - (a) Hour angle
   - (b) Zenith angle
   - (c) Surface Azimuth angle
   - (d) Declination

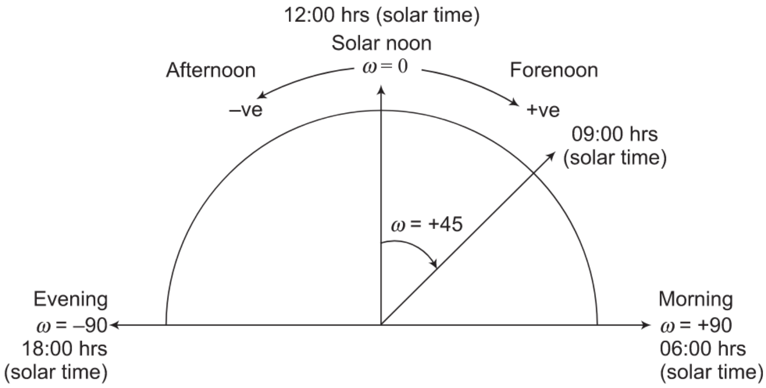
2) Write down the general equation for flux on Tilted surface and explain each term in detail. [10 marks]

3) Explain briefly the factors affecting the performance of flat plate collector. [10 marks]

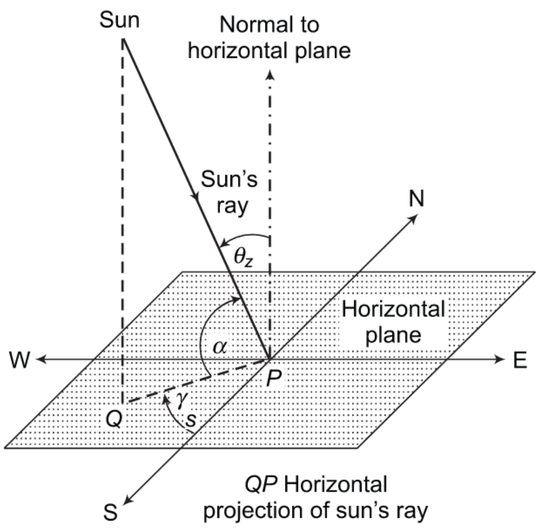
4) Explain the heat transfer process in LFPC with neat sketch and also write energy balance equation, explaining each term in it. [10 marks]

1) With relevant figures define the following:

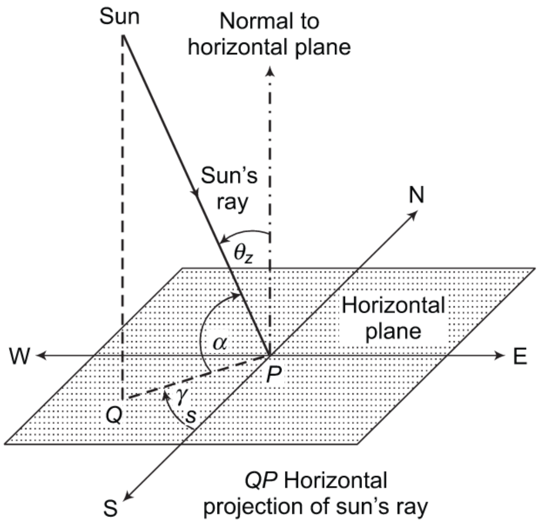
(a) Hour angle: The hour angle (ω) at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with sun's rays.



(b) Zenith angle: It is the angle between sun's ray and perpendicular (normal) to the horizontal plane. It is indicated as θ_z in the diagram below.



(c) Surface Azimuth angle: (γ_s) It is the angle on a horizontal plane, between the line due south and the projection of sun's ray on the horizontal plane. It is taken as positive when measured from south towards west.



(d) Declination: It is defined as the angular displacement of the sun from the plane of earth's equator. It is positive when measured above equatorial plane in the northern hemisphere. The declination δ can be approximately determined from the equation:

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+n)\right]$$

where *n* is the day of the year

2) Write down the general equation for flux on Tilted surface and explain each term in detail.

Total radiation incident on an inclined surface consists of three components: (i) beam radiation, (ii) diffuse radiation and (iii) radiation reflected from ground and surroundings. It may be mentioned here that both beam and diffuse components of radiation undergo reflection from the ground and surroundings. Total radiation on a surface of arbitrary orientation may be evaluated as:

$$I_T = I_b r_b + I_d r_d + (I_b + I_d)\, r_r$$

where r_b, r_d and r_r are known as tilt factors for beam, diffuse and reflected components respectively. The definitions and expressions for these factors are given below:

r_b: It is defined as the ratio of flux of beam radiation incident on an inclined surface to that on a horizontal surface.

r_d: It is defined as the ratio of flux of diffuse radiation falling on inclined surface to that on the horizontal surface. The value of this tilt factor depends upon the distribution of diffuse radiation over the sky and on the portion of the sky dome seen by the tilted surface. Assume that the sky is an isotropic source of diffuse radiation; we have for a tilted surface with slope β,

$$r_d = \frac{1+\cos\beta}{2}$$

r_r: The reflected component comes mainly from the ground and surrounding objects.
Since $(1+\cos\beta)/2$ is the radiation shape factor for tilted surface with respect to the sky, it follows that $(1-\cos\beta)/2$ is the radiation shape factor for the surface with respect to surrounding ground. Assume that the reflection of the beam and diffuse radiation falling on the ground is diffuse and isotropic and the reflectivity is p, the tilt factor for reflected radiation may be written as:

$$r_r = \rho\left(\frac{1-\cos\beta}{2}\right)$$

3) Explain briefly the factors affecting the performance of flat plate collector.

A large number of parameters influence the performance of a liquid flat-plate collector. These parameters could be classified as design parameters, operational parameters, meteorological parameters and environmental parameters. In this section, the effects of some of these will be considered. The parameters discussed are the selectivity of the absorber surface, the number of glass covers, the spacing between the covers, the tilt of the collector, the fluid inlet temperature, the transmissivity of the glass, and dust settlement on the top glass cover.

(i) Selective Surface: Absorber plate surfaces which exhibit characteristics of a high value of absorptivity for incoming solar radiation and low value of emissivity for outgoing re-radiation are called selective surfaces: Such surfaces are desirable because they maximize the net energy collection: Some examples of selective surface layers are copper oxide, nickel black and black chrome.

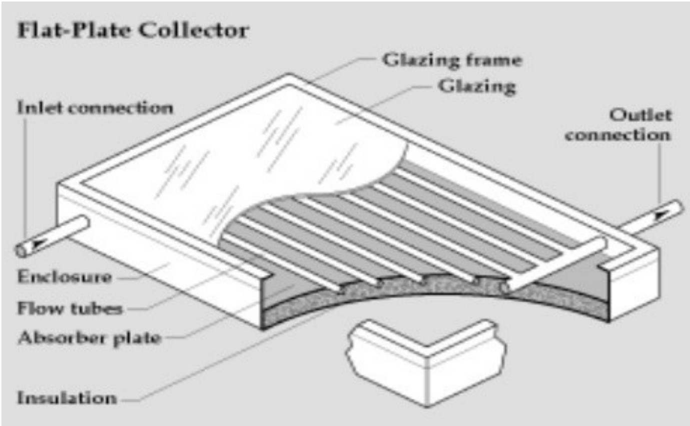
(ii) Number of Covers With increase in the number of covers, the values of both $(\tau\alpha)_b$, and $(\tau\alpha)_d$ decrease and thus the flux absorbed by the absorber plate decreases. The value of heat loss from the absorber plate also decreases. However, the amount of decrease is not the same in both cases. Maximum efficiency is obtained with one or two covers.

(iii) Spacing: Heat loss also varies with spacing between two covers and that between the absorber plate and first cover. The spacing at which minimum loss occurs varies with temperature and also with tilt. Since collectors are designed to operate at different locations with varying tilts and under varying service conditions, an optimum value of spacing is difficult to specify. Spacing in the range from 4 to 8 cm is normally suggested.

(iv) Collector Tilt: Flat-plate collectors are normally used in a fixed position and do not track the sun. Therefore, the tilt angle at which they are fixed is very important. Optimum tilt depends on the nature of the application. The usual practice is to recommend a value of (ϕ +10°) or (ϕ + 15°) for winter applications (e.g., water heating, space heating, etc) and (ϕ -10°) or (ϕ -15°) for summer applications (e.g., absorption refrigeration plant etc).

(v) Dust on the Top of the Cover: When a collector is deployed in a practical system, dust gets accumulated over it, reducing the transmitted-flux through the cover. This requites continuous cleaning of the cover, which is not possible in a practical situation. Cleaning is generally done once in a few days. For this reason, it is recommended that the incident flux be multiplied by a correction factor which accounts for the reduction in intensity because of accumulation of dust. In general, a correction factor from 0.92 to 0.99 seems to be indicated.

4) Explain the heat transfer process in LFPC with neat sketch and also write energy balance equation, explaining each term in it.



In steady state, the performance of a solar collector is described by an energy balance that indicates the distribution of incident solar energy into useful energy gain, thermal losses, and optical losses.

An energy balance on the absorber plate yields the following equation for a steady state

$$q_u = A_p S - q_l$$

in which

q_u = useful heat gain, i.e. the rate of heat transfer to the working fluid,

S = incident solar flux absorbed in the absorber plate,

A_p= area of the absorber plate, and

q_l = rate at which heat is lost by convection and re-radiation from the top, and by conduction and convection from the bottom and sides.

The flux incident on the top cover of the collector is given by $I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$. Each of the terms in the above equation is multiplied by a term called the transmissivity-absorptivity product ($\tau\alpha$) in order to determine the flux S absorbed in the absorber plate. Thus,

$$S = I_b r_b (\tau\alpha)_b + \{I_d r_d + (I_b + I_d) r_r\} (\tau\alpha)_d$$

in which,

τ= transmissivity of the glass cover system, the ratio of the solar radiation coming through after reflection at the glass-air interfaces and absorption in the glass to the radiation incident on the glass cover system,

α= absorptivity of the absorber plate,

$(\tau\alpha)_b$ = transmissivity-absorptivity product for beam radiation falling on the collector, and

$(\tau\alpha)_d$= transmissivity-absorptivity product for diffuse radiation falling on the collector.

The heat lost from the collector is the sum of the heat lost from the top, the bottom and the sides. Thus,

$$q_l = q_t + q_b + q_s$$

where

q_t = rate at which heat is lost from the top,

q_b = rate at which heat is lost from the bottom, and

q_s =rate at which heat is lost from the sides.

Each of these losses is also expressed in terms of coefficients called the *top loss coefficient* (U_t), the *bottom loss coefficient* $(U_b)$and the *side loss coefficient* $(U_s)$and defined by the equations

$$q_t = U_t A_p \left(T_{pm} - T_a\right)$$

$$q_b = U_b A_p \left(T_{pm} - T_a\right)$$

$$q_s = U_s A_p \left(T_{pm} - T_a\right)$$