2020

RANK Improvement WORKBOOK

Detailed Explanations of Objective & Conventional *Questions*

Mechanical Engineering

Renewable Source of Energy

MADE EASY Publications

1 Fundamentals of Energy, Conservation and Storage

LEVEL 1 Objective Questions

1.	(a)
2.	(a)
3.	(c)
4.	(a)
5.	(d)
6.	(d)
7.	(b)
8.	(d)
9.	(c)
10.	(b)
11.	(b)

LEVEL 2 Objective Questions

12.	(a)
13.	(c)
14.	(c)
15.	(d)
16.	(b)
17.	(c)
18.	(d)
19.	(b)
20.	(d)
21.	(d)
22.	(b)
23.	(d)

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LEVEL 3 Conventional Questions

Solution : 24

Global Warming Potential (GWP): The Global Warming Potential (GWP) is an index relative to the global warming impact of CO_2 is used to compare various greenhouse gases. The impact of the emission of the various greenhouse gases on the climate varies according to their atmospheric life. CO_2 is one of the main greenhouse gases in the atmosphere so, the GWP of CO_2 is fixed as 'one' and the global warming impact of the various gases is compared with that of CO_2. Since the atmospheric lifetime of the greenhouse gases varies therefore GWP is also time dependent. The time dependency spreads from 20 to 100 years and written as GWP_{20} (for 20 years), GWP_{100} (100 years lifetime), etc. Emission of one kg of R-134a is roughly equivalent to emission of 1300 kg of CO_2 in 100 years, so GWP100 of R-134a is 1300. Thus, the GWP of a greenhouse gas is an index relative to that of CO_2 to trap heat radiated from earth to space.

Ozone Depletion Potential (ODP) :The ozone depletion potential is defined as an index that indicates the ability of refrigerants and other chemicals to destroy stratospheric ozone molecules based on a value of 1.0 for R11.

Solution : 25

Temperature of source, $T_1 = 500 + 273 = 773$ K

Temperature of sink, $T_2 = 100 + 273 = 373$ K

Output, $W = 1$ kW

Thermal efficiency of the reversible engine,

$$\eta_{th} = 1 - \frac{T_2}{T_1} = 1 - \frac{373}{573} = 0.349$$

or $$\eta_{th} = 34.9\%$$

Now, $$\eta_{th} = \frac{W}{Q_1}$$

$$0.349 = \frac{1}{Q_1}$$

Heat supplied, $Q_1 = 2.865$ kW

Now, Heat rejected, $Q_2 = Q_1 - W = 2.865 - 1 = 1.865$ kW

Therefore, the rate of heat rejection per kW of net output = 1.865 kW.

Solution : 26

Ambient temperature, $T_1 = 40 + 273 = 313$ K

Freezer temperature, $T_2 = -10 + 273 = 263$ K

Rate of heat leakage into the freezer = 2 kJ/s

The refrigerator cycle removes heat from the freezer at the same rate at which heat leaks into it (to maintain constant temperature), thus $Q_2 = 2$ kJ/s

From minimum power requirement,

$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$

$$Q_1 = T_1 \times \frac{Q_2}{T_2} = 313 \times \frac{2}{263} = 2.38 \text{ kJ/s}$$

$$W = Q_1 - Q_2 = 2.38 - 2 = 0.38 \text{ kW}$$

Therefore, the least power required to pump the heat continuously = 0.38 kW

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2 Solar Energy Basics and Principles of Solar Radiation

LEVEL 1 Objective Questions

1.	(d)
2.	(b)
3.	(b)
4.	(b)
5.	(d)
6.	(a)
7.	(a)
8.	(b)
9.	(b)
10.	(c)
11.	(c)
12.	(d)
13.	(b)
14.	(a)
15.	(b)
16.	(b)
17.	(b)
18.	(d)

LEVEL 2 Objective Questions

19.	(c)
20.	(d)
21.	(b)
22.	(a)
23.	(c)
24.	(b)
25.	(c)
26.	(b)
27.	(b)
28.	(d)
29.	(d)
30.	(a)
31.	(c)
32.	(a)
33.	(c)
34.	(c)

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LEVEL 3 Conventional Questions

Solution : 35

(i) Local Apparent Time (LAT) can be calculated by the relation given below

$$\text{LAT} = \text{S.T.} \pm 4\,(\text{S.T. longitude} - \text{longitude of location}) + \omega_{eq} \quad \text{...(i)}$$

From the given data S.T. = 1530 h

S.T longitude (ψ_{zone}) = 82.50°

longitude of location (ψ_{local}) = 72°51′ = 72.85°

India is located in Eastern Hemisphere and hence -ve sign is applicable.

The term ω_{eq} is solved by :

$$\omega_{eq} = 229.18\,(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B) \quad \text{... (ii)}$$

and $$B = \frac{(n-1)\,360}{365}$$

For given data i.e. July 1, $n = 31 + 28 + 31 + 30 + 31 + 30 + 1 = 182$

∴ $$B = \frac{(182-1)\,360}{365} = 178.5205$$

Substituting this value into equation (2) :

$$\omega_{eq} = 229.18\,[(0.000075 + 0.001868\cos(178.5205) - 0.032077\sin(178.5205) - 0.014615\cos(357.041) - 0.04089\sin(357.041)] = -3.4618 \text{ (minutes)}$$

Substituting all the know values into equation (i) , i.e

$$\text{LAT} = 1530 - 4\,(82.50° - 72.85°) - 3.4615 = 1530 - 38.6 - 3.4618 \simeq \mathbf{1447.94\ h}$$

(ii) Hour angle can be calculated as

$$\omega = 15\,(t_{zone} - 1200) + \omega_{eq} + (\psi - \psi_{zone})$$

$$= 15\,(1447.94 - 1200) - 3.4618 \text{ minutes} + (-82.50 + 72.85)°$$

$$= 15 \times 2.8 - \frac{3.4618}{60} - 9.65 = \mathbf{32.29°}$$

Solution : 36

$$I'_{sc} = I_{sc}\left[1 + 0.033\cos\frac{360n}{365}\right] \quad \text{(Extraterrestrial solar flux)}$$

On 15th sept., n = Total number of days from 1st Jan. to 15th Sept.

$= 31 + 28 + 31 + 30 + 31 + 30 + 31 + 31 + 15 = 258$

$I_{sc} = 1367\ \text{W/m}^2$

∴ $I'_{sc} = 1354.92\ \text{W/m}^2$

Solution : 37

The declination angle (δ) is given by

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

On 21st July: $n = 31 + 28 + 31 + 30 + 31 + 30 + 21 = 202$

∴ $\delta = 20.44°$

Solution : 38

In astronomy and celestial navigation, the hour angle is one of the coordinates used in the equatorial coordinate system to give the direction of a point on the celestial sphere. The hour angle of a point is the angle between two planes: one containing the Earth's axis and the zenith (the meridian plane), and the other containing the Earth's axis and the given point (the hour circle passing through the point).

$$\text{Hour angle} = \frac{360}{24}(14.30 - 12) = 15\left(2 + \frac{30}{60}\right)$$

$$\text{Hour angle} = +37.5°$$

Solution : 39

The incidence angle of solar beam is given by for the condition prescribed

$$\cos\theta = \sin(\phi - \beta)\sin\delta + \cos(\phi - \beta)\cos\delta\cos\omega$$

Here, $\phi = \beta,\ \delta = 23.45°$ (on 21st June)

$$\omega = 15(1100 - 1200) = -15°$$

Now, $\cos\theta = 0 + 1 \times \cos 23.45° \times \cos(-15°)$

$$\theta = 27.6°$$

Solution : 40

Maximum sunshine hours are given by

$$\bar{S}_{max} = \frac{2}{15}\cos^{-1}(-\tan\phi \cdot \tan\delta)$$

Here $\phi = 23°$

For Month average of June, $n = 166$ (upto 15 June)

$$\therefore \quad \delta = 23.45\sin\left[\frac{360}{365}(284 + 166)\right]^{\circ} = 23.31°$$

$$\bar{S}_{max} = \frac{2}{15}\cos^{-1}(-\tan 23° \cdot \tan 23.31°)$$

$$= 13.41 \text{ hours}$$

Solution : 41

For given data:

$$\bar{s}_{max} = \frac{2}{15}\cos^{-1}(-\tan\phi \cdot \tan\delta)$$

$$= \frac{2}{15}\cos^{-1}(-\tan 23.58° \cdot \tan 23.31°) = 13.45 \text{ hours}$$

(tan 23.31° is the value corresponding to 15th June)

Now, $$\frac{\bar{H}_g}{\bar{H}_o} = a + b\left(\frac{\bar{s}}{\bar{s}_{max}}\right) = 0.31 + 0.48\left(\frac{8.9}{13.45}\right) = 0.6277$$

$$\bar{H}_g = 0.6277 \times 28 = 17.58 \text{ MJ}$$

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3 Solar Energy Collectors and Storage

LEVEL 1 Objective Questions

1. (b)
2. (c)
3. (d)
4. (a)
5. (d)
6. (b)
7. (d)
8. (a)
9. (b)
10. (b)

LEVEL 2 Objective Questions

11. (d)
12. (d)
13. (b)
14. (d)
15. (a)
16. (c)
17. (c)
18. (d)
19. (c)
20. (d)
21. (d)
22. (a)
23. (a)
24. (c)
25. (b)
26. (c)
27. (b)

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LEVEL 3 Conventional Questions

Solution : 28

Location latitude, $\phi = 32°$

Day no., $n = 31 + 28 + 30 = 89$ (Mar, 30)

Then, declination angle, $\delta = 23.45 \sin\left\{\frac{360}{365} \times (284 + n)\right\} = 3.22°$

NOTE: Where n is the day in the year (n = 1 on 1 January). The error for a leap year is insignificant in practice.

whereas for sunset and sunrise hour angle,

$$\cos\theta = \sin\delta - \sin\phi + \cos\delta \times \cos\phi \times \cos\omega$$

we need to put, $\theta = 90°$

(at sunset, the sunlight is parallel to the ground surface with a zenith angle of 90°)

$$0 = \sin\delta \times \sin\phi + \cos\delta \times \cos\phi \times \cos\omega_s$$

$$\Rightarrow \quad \cos\omega_s = -\tan\delta \times \tan\phi$$

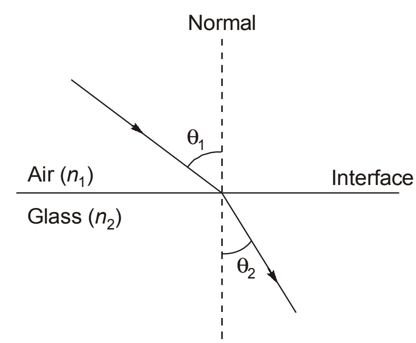
$$\omega_s = \cos^{-1}(-\tan\delta \times \tan\phi)$$

$$\omega_s = 92.01$$

Hence for day-length, $t_{day} = 2 \times \frac{\omega_s}{15}$ hours $= 12.27$ hours

Solution : 29

According to law,



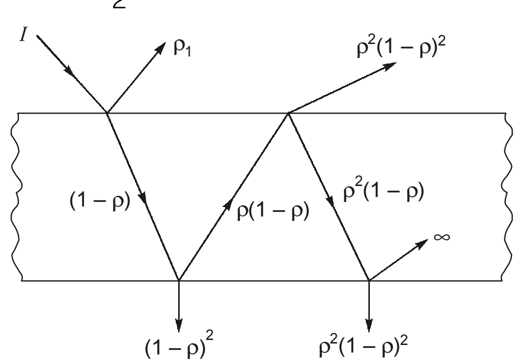
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \times \sin\theta_1\right)$$

where, $\rho = \frac{1}{2}(\rho_1 + \rho_2)$

$$\rho_1 = \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} \text{ and } \rho_2 = \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)}$$

Similarly, $\tau = \frac{1}{2}(\tau_1 + \tau_2)$



$$\tau = (1-\rho)^2 + \rho^2(1-\rho)^2 + \rho^4(1-\rho)^2 + \ldots\infty$$

$$\tau = \frac{(1-\rho)^2}{1-\rho^2}$$

$$\Rightarrow \qquad \tau = \frac{1-\rho}{1+\rho}$$

for

$$\tau_1 = \frac{1-\rho_1}{1+(2M-1)\rho_1}$$

$$\tau_2 = \frac{1-\rho_2}{1+(2M-1)\rho_2}$$

$$\tau = \frac{1}{2}(\tau_1+\tau_2)$$

for numerical data:

$$\theta_1 = 45°;\ \frac{n_1}{n_2} = \frac{1}{1.5};\ M = 2$$

$$\theta_2 = \sin^{-1}\left(\sin\theta_1 \times \frac{n_1}{n_2}\right) = 28.125$$

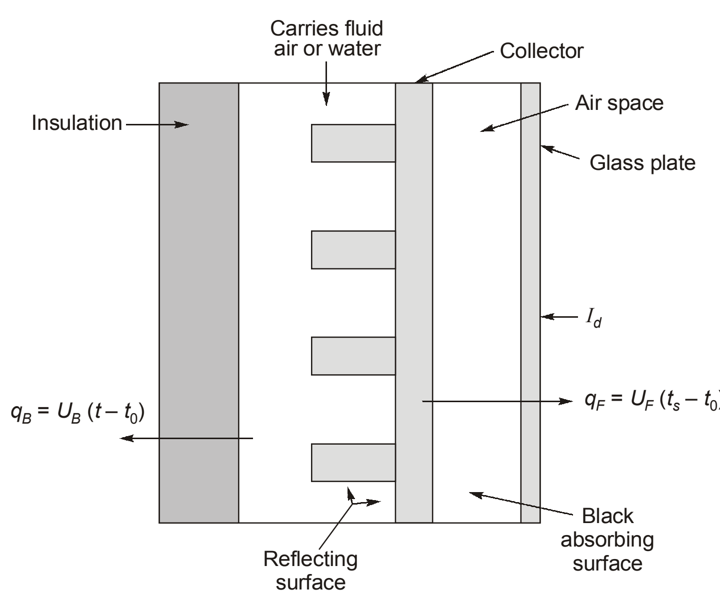
$$\rho_1 = 0.092;\ \rho_2 = 0.008$$

then,

$$\tau_1 = 0.712;\ \tau_2 = 0.968$$

$$\tau = \frac{1}{2}(\tau_1+\tau_2) = 0.84$$

Solution : 30



Heat loss occurs from

(1) Cover plate (Q_B)

(2) Back side (Q_F)

(3) Sides of collector box (Negligible)

Let U_F and U_B be the overall heat transfer coefficient from plate to ambient from front side, and from fluid to ambient from back side.

$t_0,\ t_s,\ t =$ Ambient, plate surface and fluid temperature

Consider an elemental plate surface area dA over which the temperature of the fluid rises by dt, we have:

$$\dot{m}cdt = \frac{U_o A_o}{A} dA(t_s - t) - U_B dA(t - t_o)$$

where
$\dot{m}$ = mass flow rate of carrier fluid
C = specific heat
A = collector surface area
A_o = Extended surface area on the side of fluid

and Collector efficiency $= \dfrac{\text{Heat collected/ Area}}{\text{Solar intensity}}$

Solution : 31

As Extra terrestrial flux, $I'_{sc} = I_{sc}\left(1 + 0.033\cos\dfrac{360n}{365}\right)$

On 2 march,

n = total number of days from Jan. 1
$= 31 + 28 + 2 = 61$

$$\Rightarrow \quad I'_{sc} = 1367\left(1 + 0.033\cos\frac{360n}{365}\right)$$

$$= 1367\left(1 + 0.033 \times \frac{1}{2}\right) \simeq 1389 \text{ W/m}^2$$

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4 Solar Photovoltaic System

LEVEL 1 Objective Questions

1.	(c)
2.	(a)
3.	(a)
4.	(d)
5.	(b)
6.	(c)
7.	(a)
8.	(c)
9.	(a)
10.	(a)

LEVEL 2 Objective Questions

11.	(b)
12.	(c)
13.	(c)
14.	(d)
15.	(*)
16.	(c)
17.	(b)
18.	(d)

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LEVEL 3 Conventional Questions

Solution : 19

Output power required,

$$P_{motor} = 1 \text{ hp} = 735 \text{ W}$$

Input power required, $P_{required} = \dfrac{P_{motor}}{\eta_{motor}} = 864.7$ W

Wherease, cell area in one module,

$$A_m = 9 \times 4 \times 125 \times 125 \times 10^{-6}$$

$$A_m = 0.5625 \text{ m}^2$$

Assumed, no. of modules to be 'N'.

Solar radiation incident on panel,

$$I_g = 1 \text{ kW/m}^2 = 1000 \text{ W/m}^2$$

$$\eta_{conv.} = 0.12$$

Output of solar array, $P_{out} = 1000 \times 0.5625 \times N \times 0.12$

Where,

$$1000 \times 0.5625 \times N \times 0.12 = 67.5 \times N = 864.7 \text{ W}$$

Minimum number of modules, $N = 12.8 \simeq 13$

Solution : 20

As per the photoelectric effect,

$$I = I_{sc} - I_o\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$$

for V_{oc}, the current supply, $I = 0$

$$0 = I_{sc} - I_o\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$$

where, $e = 1.602 \times 10^{-19}$ J/V

Dark-current, I_o

$$\Rightarrow \quad I_o = \frac{I_{sc}}{\left[\exp\left(\frac{eV}{kT}\right) - 1\right]} = 5.502 \times 10^{-8} \text{ A/m}^2$$

For Pmax conditions,

$$P = V \times I$$

$$P = V \times \left\{I_{sc} - I_o\left[\exp\left(\frac{eV}{kT}\right) - 1\right]\right\}$$

$$\frac{dP}{dV} = 0$$

$$\frac{dP}{dV} = I_{sc} - I_o\left\{\exp\left(\frac{eV_m}{kT}\right) - 1\right\} - \frac{eV_m}{kT} \times I_o \times \exp\left(\frac{eV_m}{kT}\right) = 0$$

$$\Rightarrow \quad \left(1 + \frac{eV_m}{kT}\right)\exp\left(\frac{eV_m}{kT}\right) = 1 + \frac{I_{sc}}{I_o}$$

After solving,

$$V_m = 0.519 \text{ V}$$

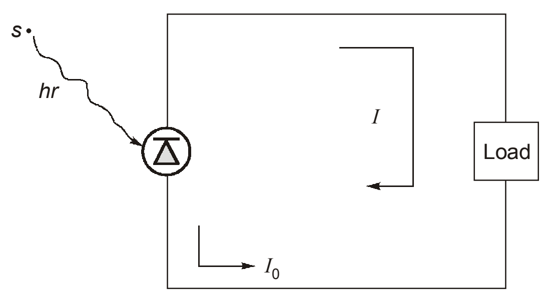
Similarly,

$$I_m = \frac{\left(\frac{eV_m}{kT}\right) \times (I_{sc} + I_o)}{\left(1 + \frac{eV_m}{kT}\right)} = 237.6 \text{ A/m}^2$$

$$P_m = I_m \cdot V_m = 123.3 \text{ W/m}^2$$

$$F.F. = \frac{I_m \cdot V_m}{I_{sc} \cdot V_{oc}} = 0.822$$

$$(P_{max})_{actual} = P_m \times A_c = 123.3 \times \frac{(10 \times 10)}{100 \times 100} = 1.233 \text{ W}$$



Solution : 21

Causes of low efficiency of a solar cell: The efficiency of a photovoltaic cell is 15% only. The major losses which lead to the low efficiencty of the cell are:

1. As the temperature of the cell rises due to solar radiation, leakage across the cell increases. Consequently, power output, relative to solar energy input, decreases. For silicon, the output decreases by 0.5% per °C.
2. The excess energy of active photons given to the electrons beyond the required amount to cross the band gap cannot be recovered as useful electric power. It appears as heat, about 33 percent, and is lost.
3. The electric current (generated) flows out of the top surface by a mesh of metal contacts provided to reduce series resistance losses. These contacts cover a definite area which reduces the active surface and proves an obstacle to incident solar radiation.

Solution : 22

Solar cells can be classified on the basis of:

1. Cell size;
2. Thickness of active material;
3. Type of junction structure;
4. Type of active material.

1. **Cell size:** The size of the silicon solar cell can be divided into four groups;

(i) Round single crystalline having 100 mm diameter;
(ii) Square single crystalline having area of 100 cm^2,
(iii) 1000 mm × 1000 mm square multicrystalline, and
(iv) 125 mm × 125 mm square multicrystalline.

Larger size solar cells are used in terrestrial applications. Due to brittleness property of the silicon, area of silicon solar cells in limited.

2. **Thickness of active material:** Such solar cells are of two types:
   (i) Bulk material cell, and
   (ii) Thin film cell.

   Bulk material single crystal and multicrystalline cells are most successful for terrestrial applications. **Thin film** cells are not commercially successful.
3. **Type of junction structure:** These cell are classified as:
   (i) p-n homojunction cell,
   (ii) p-n hetrojunction cell,
   (iii) p-n multijunction cell, and
   (iv) Metal semiconductor Schottky junction.
4. **Type of active material:** Such cell are classified as:
   (i) Single crystal silicon cell,
   (ii) Multicrystalline silicon cell,
   (iii) Amorphous silicon cell,
   (iv) Gallium arsenide cell.

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5 Wind Energy

LEVEL 1 Objective Questions

1.	(d)
2.	(a)
3.	(a)
4.	(c)
5.	(a)
6.	(c)
7.	(b)
8.	(d)
9.	(c)
10.	(c)
11.	(a)
12.	(a)
13.	(d)
14.	(c)
15.	(b)
16.	(b)
17.	(c)

LEVEL 2 Objective Questions

18.	(a)
19.	(d)
20.	(a)
21.	(d)
22.	(b)
23.	(a)
24.	(d)
25.	(b)
26.	(b)
27.	(b)
28.	(c)
29.	(d)
30.	(d)
31.	(c)
32.	(c)

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LEVEL 3 Conventional Questions

Solution : 33

As wind-velocity is varied by power-law,

$$U_H \propto (H)^\alpha$$

$$\frac{U_H}{U_{H_1}} = \left(\frac{H}{H_1}\right)^\alpha$$

$$\Rightarrow \quad U_H = U_{H_1} \times \left(\frac{100}{10}\right)^\alpha$$

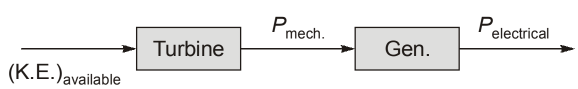
(i) $$U_H = 16.565 \text{ m/s}$$

(ii) $$P_{total} = \frac{1}{2}\rho A_b \cdot U_H^3 = 14.005 \text{ MW}$$

$$A_b = \frac{\pi}{4} \times D^2 = 5026.55 \text{ m}^2$$

(iii) $$(P_{turbine})_{max} = C_p \cdot P_{total} = 0.593 \times P_{total} = 8.305 \text{ MW}$$

(iv) For electrical power generation,



$$(\text{EP})_{gen} = P_{mech} \times \eta_{gen} = 7.059 \text{ MW}$$

$$(v)_{\text{Blade tip ratio}}, \lambda = \frac{U_{bt}}{U_w} = 9.5$$

$$\lambda = \frac{\omega R}{U_w}$$

$$\Rightarrow \quad \omega = \frac{\lambda \cdot U_w}{R} = 3.934 \text{ rad/s}$$

$$\omega = \frac{2\pi N}{60} = 3.934 \text{ rad/s}$$

$$N = 37.569 \text{ rpm}$$

Solution : 34

Given: $V_1 = 4.472$ m/s

Speed at turbine rotor, $V_2 = 60\% \times V_1 = 0.6 \times 4.472 = 2.6832$ m/s

Speed at exit, $V_3 = 0.3 \times 4.472 = 1.3416$ m/s

$$\rho = 1.293 \text{ kg/m}^3$$

$$D_2 = 9 \text{ m}$$

$$A_2 = \frac{\pi}{4} D_2^2$$

Solution : 35

$$\text{Wind energy available, } (P) = \frac{1}{2}\rho A_s V^3$$

$$\frac{P}{A_s} = \frac{1}{2}\rho V^3$$

Now $\rho = \dfrac{1.013 \times 10^5}{287 \times 300} = 1.18 = \dfrac{1}{2} \times 1.18 \times 6^3 = 127.32$

Maximum power extracted by turbine = 0.593 × $P_{available}$ = 0.593 × 127.32 = 75.5 W/m^2

Solution : 36

The relation between power coefficient and axial induction factor is given by

$$c_p = 4a(1 - a)^2$$

To obtain the maximum value of c_p, we have

$$\frac{d(c_p)}{da} = 0$$

$$-8a(1 - a) + 4(1 - a)^2 = 0$$

$$(1 - a)(-8a + 4 - 4a) = 0$$

$$\text{Either } a = \frac{4}{12} = \frac{1}{3}$$

or $a = 1$

Since value of a cannot be 1.

$$a = \frac{1}{3}$$

Solution : 37

As, Power to lift water = $P = \rho gQH$

$$= 1000 \times 9.81 \times \frac{7.2}{3600} \times 9 = 176.58 \text{ W}$$

So, power required from wind machine

$$P_w = \frac{P}{\eta_p \times \eta_t} = \frac{176.58}{0.5 \times 0.8}$$

$\Rightarrow$ $P_w = 441.45$ W

Solution : 38

Basic components of wind energy conversion system (WECS)

- **Wind turbines** (Aeroturbines) convert the energy of moving air into rotary mechanical energy. These turbines requires pitch and yaw controls for proper operation.
- A **mechanical interface** consisting of a step up gear and a suitable coupling transmits the rotary mechanical to an **electrical generator.** The output of this generator is connected to the road or power grid as the application demands.

- A **controller** serves purposes of sensing:
  (i) Wind speed,
  (ii) Wind direction, shafts speed and torques at one or more points,
  (iii) Output power and generator temperature,
  (iv) Appropriate control signals for matching the electrical output to the wind energy input and
  (v) Protect the system from extreme conditions brought about by strong winds, electrical faults etc.

Solution : 39

Advantages and disadvantages of wind energy conversion systems (WECS): the advantages and disadvantages of wind energy conversion system as follows:

Advantages:

1. Wind energy, a renewable energy source, can be tapped free of fuel cost.
2. The wind turbine generation (WTG) produces electricity which is environmentally friendly.
3. Wind power generation is cost effective.
4. It is economically competitive with other modes of power generation.
5. Quite reliable.
6. Electric power can be supplied to remote inaccessible areas.

Disadvantages:

1. As the wind speed is variable, wind energy is irregular, unsteady and erratic.
2. Wind turbine design is complex.
3. Wind energy systems requires storage batteries which contribute to environmental pollution.
4. Wind energy systems are capital intensive and need government support.
5. Wind energy has low energy density and normally available at only selected geographical locations away from cities and load centers.
6. For wind farms (which are located in open areas away from load centres), the connection to state grid is necessary.
7. 'Large units' have less cost per kWh, but require capital intensive technology. In contrast 'small units' are more reliable but have higher capital cost per kWh.

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6 Biomass Energy

LEVEL 1 Objective Questions

1. (c)
2. (c)
3. (a)
4. (c)
5. (d)
6. (c)
7. (d)
8. (b)
9. (c)
10. (a)

LEVEL 2 Objective Questions

11. (d)
12. (b)
13. (d)
14. (b)
15. (c)
16. (c)
17. (c)
18. (a)
19. (d)
20. (c)

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LEVEL 3 Conventional Questions

Solution : 21

Amount of dry matter = 2.5 kg/day

$$\text{Amount of cow dung per day} = \frac{2.5}{0.25} = 10 \text{ kg}$$

∴ To make slurry, equal amount of water is required, so total amount of slurry produced per day

$$= 10 \times 2 = 20 \text{ kg}$$

Solution : 22

$$\text{Power required} = \frac{P_g}{\eta_E} = \frac{210}{0.35} = 600 \text{ kW}$$

Power delivered by biomass = 0.80 × 600 = 480 kW

$$\eta_{\text{gasifier}} = \frac{P_{\text{Biomass}}}{\dot{m} \times C.V.}$$

or $$\dot{m} = \text{Feedrate of biomass} = \frac{480}{0.75 \times 16000}$$

⇒ $$\dot{m} = 0.04 \text{ kg/s}$$

or $$\dot{m} = 144 \text{ kg/h}$$

Solution : 23

Environmental benefits/effects of biomass/biofuel

Following are the benefits/effects of biomass/biofuels:

1. Biomass can pollute air when it is burned but less than those of fossil fuels.
2. Burning biofuels do not produce pollutants like sulphur, that results in acid rain.
3. When biomass crops are grown, nearly equivalent amount of CO_2 is captured through photosynthesis.

Solution : 24

Application of biogas in petrol engines:

- Biogas can be used in petrol engines after initial starting of the engine on petrol. It needs about 550 litres of gas per kWh to run a petrol engine.
- Engine can also run a duel fuel engine either on biogas or petrol. It has the advatage that the engine can run on petrol if the biogas is not available or vice-versa.

Application of biogas in "Diesel engines":

- Biogas can be better used in diesel engines (as a duel fuel engine).
- It is more convenient to used biogas since it has high self ignition temperature of about 730°C.

Application of using biogas in engines:

1. It has ample flexibility of operation.
2. A uniform gas-air mixture is available in multicylinder engines.
3. Clean combustion reduces the wear of engine parts.
4. Lubricating oil consumption is reduced.
5. Emissions of CO are greatly reduced.
6. NO_x emissions are also reduced.

Solution : 25

Factors affecting generation of biogas

The generation of biogas is affected by the following factors:

1. Temperature,
2. Loading rate,
3. Solid concentration,
4. pH value,
5. Retention period,
6. Toxic substances.

1. **Temperature:** The anaerobic fermentation process is temperature dependent. The process of the digestion and gasification proceeds at the highest rate when the temperature lies between 35°C – 38°C.
2. **Loading rate:** "Loading rating" is the weight of volatile solids fed to a digester per day. It depends upon the plant capacity and also the retention period.
3. **Solid concentration:** Normally, 7 to 9 parts of solid in 100 parts of the slurry is considered ideal.
   - It is recommented that 4 parts of the cattle dung to be mixed with 5 parts of water.
4. **pH Value:** pH denotes the acidity and alkalinity of the substrate. The pH less than 7 is called 'acidic' and pH more than 7 is called 'alkaline' and pH solution of 7 is called 'neutral'.
5. **Retention period:** It is the time period for which fermentable material resides inside the digester. This period ranges from 30 days to 50 days depending upon the climatic conditions.
   - Generally it is observed that maximum gas production takes place within 'first four weeks' and it tapers off gradually.
6. **Nutrients concentration:** The major nutrients required by the bacteria in the digester are C, H_2, O_2, N_2, P and S. To maintain proper balance of nutrients an extra raw material, rich in P and N_2, should be added along with cattle dung to obtain maximum gas production.
7. **Toxic substance:** The presence of ammonia, pesticides, detergents and heavy metals are considered as toxic substances to micro-organisms, since their presence reduces fermentation rate.

Solution : 26

Main components of a biogas plant

The main components of a biogas plant are enumerated and briefly described below:

1. Digester,
2. Gas holder,
3. Inlet,
4. Outlet,
5. Slurry mixing tank;
6. Gas outlet pipe;
7. Stirrer.

1. **Digester:** A digester is also called 'fermentation tank' and is mostly embeded partly or fully in the ground. It is generaly cylindrical in shape and is made of bricks. It holds the slurry for a sufficiently long time to complete the digestion.
2. **Gas holder:** Its function is to keep the gas for subsequent use. The gas connection for use is taken from the top of the gas holder. In some designs of biogas plants, it may be separable from the digester whereas in other desings it may be an integral part of the digester.
3. **Inlet:** An inlet is provided to add the mixture of dung and water to the digester, and is slope.
4. **Outlet:** The provision of an outlet is made to take out the digester portion of slurry.
5. **Slurry mixing tank:** This tank carries out mixing of the dung with water or induction in the digester, through the inlet.
6. **Gas outlet pipe:** It is used for taking out gas from the gas holder and is connected to its top. The other end of the pipe is connected with the device using biogas.
7. **Stirrer:** The stirrers are provided in biogas plants of large size for stirring the slurry for fermentation inside the fermentation chamber to ensure the normal production of gas.

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7 Tidal Energy and Fuel Cells

LEVEL 1 Objective Questions

1.	(b)
2.	(b)
3.	(c)
4.	(c)
5.	(c)
6.	(d)
7.	(c)
8.	(b)
9.	(d)
10.	(a)

LEVEL 2 Objective Questions

11.	(d)
12.	(c)
13.	(b)
14.	(c)
15.	(b)
16.	(a)
17.	(b)
18.	(b)
19.	(a)

■■■■

LEVEL 3 Conventional Questions

Solution : 20

Given: Amplitude $R = 13$ m

$r = 3$ m

Basin area, $A = 2$ km^2

Gen. turb, $\eta = 0.7$

Density of sea water may be assumed as

$$\rho = 1025 \text{ kg/m}^3$$

$$= 0.225 \times A(R^2 - r^2) \text{ watts}$$

$$= 0.225 \times 2 \times 10^6 \times (13^2 - 3^2)$$

$$= 72 \text{ MW}$$

Average power generated $= 72 \times 0.7 = 50.4$ MW

$$\text{Energy available in single emptying} = \frac{1}{2}\rho Ag(R^2 - r^2)$$

$$= \frac{1}{2} \times 1025 \times 2 \times 10^6 \times 9.8 \times (13^2 - 3^2)$$

$$= 1607200 \text{ MJ}$$

One ebb cycle duration $= 12$ h 25 min $= 12.42$ h

$$\text{Number of ebb cycles in a year} = 365 \times \frac{24}{12.42} = 705.5 \approx 706$$

Average annual energy generation $= 1607200 \times 706 \times 0.7$J

$$= 2.2 \times 10^8 \text{ kWh}$$

Solution : 21

$$\Delta H^\circ = -56.8 \times 4.184 = -237.651 \text{ kJ/mol}$$

$$\Delta G^\circ = -39.59 \times 4.184 = -165.644 \text{ kJ/mol}$$

As per the 1st law and 2nd law of thermodynamic,

$$\Delta W_{max} = -\Delta G = 165.644 \text{ kJ}$$

i.e. 165.644 kJ electrical work is produced from 1 mole (i.e. 32 g) of methanol of and $\frac{3}{2}$ (mole i.e. 1.5×32 g) of O_2.

i.e. with $\dot{M}_{methane} = 32$ g/s

$\Rightarrow$ $\dot{W}_{output} = 165.644$ kJ/sec

$$(\dot{M}_{methnol})_{required} = \left(\frac{165.644}{100}\right)^{-1} \times 32 = 19.32 \text{ g/s} = 69.264 \text{ kg/h}$$

$$\left(\dot{M}_{O2}\right)_{required} = \frac{100}{165.644}\times 48 = 28.98 \text{ g/s} = 104.32 \text{ kg/h}$$

Heat transferred, $\Delta Q = T\Delta S = \Delta H° - \Delta G°$

$$= -56.83 + 39.59 = -17.24 \text{ Kcal/mol}$$

'–ve' sign for heat rejection.

Heat produce for 19.32 g/sec of methanol is

$$(\Delta Q)_{actual} = -17.24\times\frac{19.32}{32} = -10.408 \text{ kcal/sec}$$

$$(\Delta Q)_{actual} = 43.549 \text{ kJ/sec (kW)}$$

$$\eta_{conv.} = \frac{\Delta G°}{\Delta H°} = 0.697 \simeq 69.7\%$$

$$\Delta W_{max} = (\eta_{conv.})_{max.}\times\Delta H° = 165.732 \text{ kJ/mol}$$

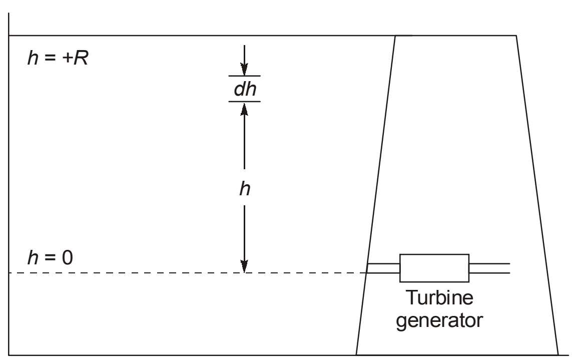
Solution : 22

Tidal range (amplitude), 'R' and certain head '*h*' at given time during the flow from ocean to basin, the differential work done (dW) is equal to change in potential energy.

$$dW = dmgh \quad \text{...(1)}$$

$$dm = -\rho A dh \quad \text{...(2)}$$

$$W_{emp} = \int_R^0 dW = \int_R^0 -\rho Agh\times dh$$



$$W_{emp} = \frac{\rho gAR^2}{2} \text{ Joule}$$

Hence, $W_{emp} \propto R^2$

Data: A = 40 km^2; R = 10 m; n = 3 m; η_{tg} = 75%; ρ = 1025 kg/m^3

$$W_{emp} = \int_R^n dW = \int_{h=R}^{h=3} (-\rho Adh)gh$$

$$W_{emp} = \frac{\rho Ag}{2}\times\left(R^2 - h^2\right)J$$

$$W_{emp} = 18300.5 \text{ GJ}$$

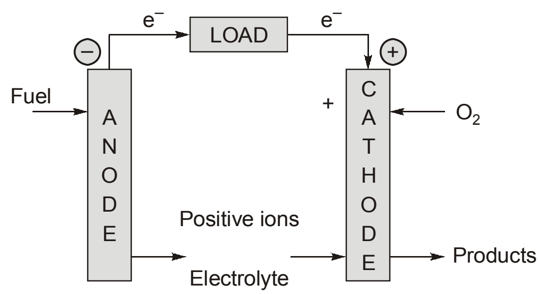
$$\rho_{avg} = \frac{W_{emp}}{\text{time}} = \frac{W_{emp}}{22350\,\text{sec}} = 818.817 \text{ MW}$$

Solution : 23

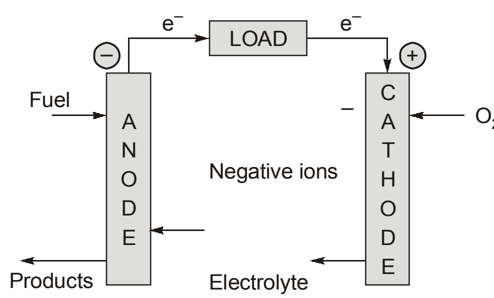
In a fuel cell, the type of reactions taking place is determined by the fuel and oxidizer combination, by the composition of the electrolyte, and the materials and the catalytic effect of cathode and the anode surfaces.

The three different types of fuel-cell reaction are –

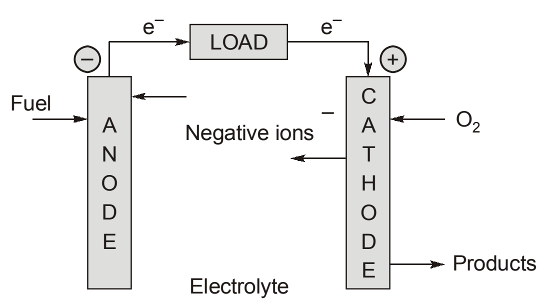
(1) Type A



(2) Type B



(3) Type C



Hydrogen-oxygen fuel cell reactions, (Type A)

Anode : $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode : $4e^- + O_2 + 4H^+ \rightarrow 2H_2O\ (l)$

Cell : $2H_2 + O_2 \rightarrow 2H_2O\ (l)$

for (Type C)

Anode : $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Cathode : $2O_2 + 4H_2O + 4e^- \rightarrow 2HO_2^- + 2OH^- + 2H_2O \rightarrow 4OH^- + O_2 + 2H_2O\ (l)$

$\therefore \quad O_2 + 4H_2O + 4e^- \rightarrow 4OH^- + 2H_2O\ (l)$

Cell : $2H_2 + O_2 \rightarrow 2H_2O\ (l)$

Carbon-Oxygen fuel cell, Type B

Anode : $C + 2O^{2-} \rightarrow CO_2 + 4e^-$

Cathode : $4e^- + O_2 \rightarrow 2O^{2-}$

Cell : $C + O_2 \rightarrow CO_2\ (g)$

Methane - oxygen fuel cell —

Anode : $CH_4 + 2H_2O \rightarrow CO_2 + 8e^- + 8H^+$

Cathode : $8e^- + 8H^+ + 2O_2 \rightarrow 2H_2O(l) + 2H_2O$

Cell : $CH_4 + 2O_2 \rightarrow CO_2\ (g) + 2H_2O\ (l)$

Solution : 24

Given: $A = 24\ km^2 = 24 \times 10^6\ m^2$; $R = 10$ m; $r = 3$ m (the heat before turbine stops operating); $\eta = 0.75$; $\rho = 1025\ kg/m^3$; $g = 9.81\ m/s^2$.

Average power generated, P_{av}:

$$\text{Work done, } W = \int_R^r -g\rho A h dh = -g\rho A \int_R^r h dh = \frac{1}{2} g\rho A(R^2 - r^2) \qquad \text{... (i)}$$

Thus, Average power generation,

$$P_{av} = \frac{W}{\text{Time}} = \frac{g\rho A(R^2 - r^2)}{2 \times 22350}$$

$$= \frac{1}{44700} \times 9.81 \times 1025 \times (24 \times 10^6)(10^2 - 3^2) \times 10^{-6}\ \text{MW}$$

or, $\quad MW = 491.3$ MW

$\therefore \quad$ Power generated $= 491.3 \times 0.75 = 368.5$ MW

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