MECHANICAL ENGINEERING

Renewable Sources of Energy

Comprehensive Theory
with Solved Examples *and* Practice Questions

MADE EASY PUBLICATIONS

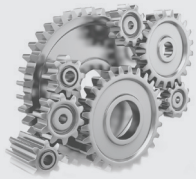
www.madeeasypublications.org

MADE EASY Publications Pvt. Ltd.

Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016 | **Ph. :** 9021300500

Email : infomep@madeeasy.in | **Web :** www.madeeasypublications.org

Renewable Sources of Energy



EDITIONS

First Edition : 2015
Second Edition : 2016
Third Edition : 2017
Fourth Edition : 2018
Fifth Edition : 2019
Sixth Edition : 2020
Seventh Edition : 2021
Eighth Edition : 2022
Ninth Edition : 2023

Tenth Edition : 2024

CONTENTS

Renewable Sources of Energy

CHAPTER 5

CHAPTER 6

CHAPTER 7

CHAPTER 8

CHAPTER

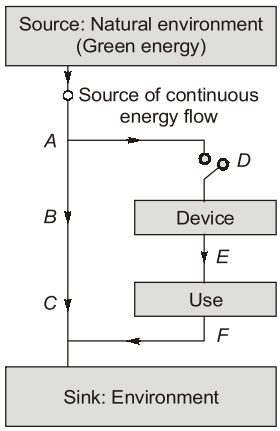
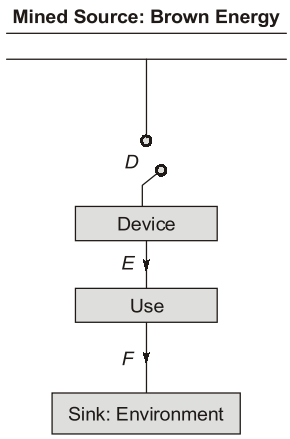
1

Introduction

1.1 RENEWABLE ENERGY

Renewable energy is the term used for energy flows occurring naturally and repeatedly at a rate such that it is replenished at the same rate as they are used. The ultimate sources of renewable energy are : Sun, gravity and rotation of earth. Energy from these resources is derived in various forms such as solar, wind, tidal, biomass etc.

1.2 DIFFERENCE BETWEEN RENEWABLE AND NON-RENEWABLE SOURCES OF ENERGY

Renewable Sources	Non-Renewable Sources
1. Energy obtained from natural and persistent flows of energy occurring in the immediate environment is renewable energy.	1. Energy obtained from static stores of energy that remained underground unless released by human interaction is known as non-renewable energy.
2. Examples: Solar, Wind, Hydro power, Biomass, Tidal, Ocean thermal.	2. Example: Nuclear fuels, fossil fuels of coal, oil, natural gas.
3. This type of energy is already passing through the environment as flow or current, irrespective of the fact that there is any device present to harness this energy or not.	3. This type of energy is initially in the form of isolated source potential. An external (human) action is required to start the supply of energy for practical purposes.
4. Other names : Green Energy, Sustainable energy.	4. Other names: Finite supplies, Brown energy.
5. Energy Flow Diagram	5. Energy Flow Diagram
	
ABC → Environmental energy flow. *DEF* → Harnessed energy flow.	*DEF* → Extracted energy from brown energy source.

EXAMPLE : 1.1

For which of the following sources, Sun is not an indirect source of energy?

(a) Wind energy (b) Tidal energy

(c) Biomass energy (d) Fossil fuels

Solution: (b)

1.3 AVAILABILITY OF RENEWABLE ENERGY ON EARTH

The Energy flux received per square meter on the surface of the earth is 500 W (approximately) from all the sources of renewable energy. The demand of energy per person is 2 kW, considering the requirements of modern society. If renewable energy flux is harnessed at just 4% efficiency, 2 kW of the power required can be drawn from an area of 10×10 m^2 with suitable method of power harnessing. The total energy demand can be fulfilled by using just 5% of the local land area.

The major contribution in the renewable energy comes from solar energy. The total solar flux absorbed at the sea level is about 1.2×10^7 W. Thus, the availability of solar flux per person on Earth's surface is 20 MW which is 10,000 times compared to the requirement of energy per person.

Thus, it can be said that renewable energy source has the potential to cater the demand of energy globally, but only if the technical methods and institutional frameworks exist to extract, use and store the energy in an appropriate form at realistic costs.

EXAMPLE : 1.2

Consider the following statements regarding spectral distribution of solar radiation :

1. Solar flux is non-uniformly distributed over a wave length in which it covers the entire range of visible radiation and some part of ultraviolet and infrared radiation.
2. It is having maximum energy distribution in infrared region.
3. It is having maximum spectral emissive power in the visible radiation region as per Planck's distribution.

Which of the above statements are correct?

(a) 1 and 2 (b) 2 and 3

(c) 1 and 3 (d) 1, 2 and 3

Solution: (d)

OBJECTIVE BRAIN TEASERS

Q.1 Renewable energy resources supply
1. Continuous energy
2. Intermittent energy
3. Replenishable energy
4. Non-replenishable energy

(a) 1 and 4 (b) 2 and 3
(c) 1 and 3 (d) 2 and 4

Q.2 Which are the renewable energy resources?
1. Solar energy 2. Natural gas
3. Biogas 4. Geothermal energy

(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) All of these

Q.3 An erupted volcano is precisely an example of :
(a) geothermal energy
(b) renewable energy
(c) fossil fuel energy
(d) non-renewable energy

Q.4 Which of the following statements are true regarding a renewable energy resource?
1. It is replenishable and a clean form of energy
2. Available in abundant but in dilute form
3. It can easily be harnessed without investing much money in establishment of plants.
4. Reliable source of energy

(a) 1 and 2 (b) 1, 2 and 3
(c) 1, 2 and 4 (d) All

Q.5 Which one of the following renewable energy resources have maximum available energy flux
(a) Solar radiation (b) Wind power
(c) Geothermal (d) Tidal energy

Q.6 The maximum contribution in fulfilling world energy consumption is done by :
(a) Coal (b) Oil
(c) Natural gas (d) Solar energy

Q.7 The maximum contribution in power production by renewable energy sources comes from :
(a) Wind (b) Solar
(c) Geothermal (d) Biogas

ANSWER KEY

1. (b) 2. (c) 3. (a) 4. (c) 5. (a)
6. (a) 7. (a)

■■■■

CHAPTER

2

Solar Radiation

2.1 INTRODUCTION

Solar energy is one of the most promising source of renewable energy. Typically the power of the Sun intercepted by the Earth is approximately 1.8×10^{11} MW. This much power is sufficient enough to cater the need of world power consumption even if harnessed at an efficiency of 0.01%. Apart from a large source of energy, solar energy has two more factors in its favour. The first one is, it is clean/green energy and second one is its availability over all the parts of earth which are suitable for living.

Unlike any other source of energy, solar energy is also available in dilute form. Solar radiation flux rarely exceeds 1 kW/m^2 even in the hottest regions on earth. Total radiation over a day reaches to 7 kWh/m^2 at its best. As a consequence, large collector area is required to fulfil the need of industry or household applications, which in turn raises its cost more than the cost incurred by conventional energy resources. Now a days because of the government policies, subsidies are given to setup solar energy harnessing units so that its cost can be brought comparable to the existing energy cost.

Solar energy can be utilized directly or indirectly. Direct methods involve heating of water/air, drying of commodities and conversion into electricity using photovoltaic cells.

Indirect methods of solar energy drives ecological systems. Hydropower is the most utilized indirect method of solar energy. In case of hydropower, water is evaporated from various sources and it falls back on earth in the form of rain. Dams are made in the pathways of river to generate electricity. Other indirect ways are wind energy, biomass energy, wave energy, etc.

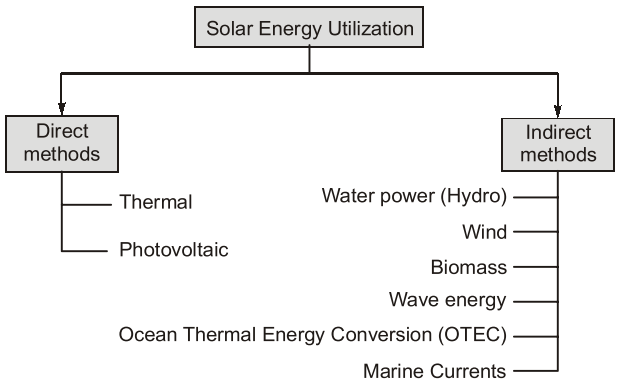


Fig: Utilization of Solar Energy

These methods are shown graphically in the given figure. Before proceeding to the utilities of solar energy, one has to understand how solar energy is received on earth and how atmosphere of Earth interacts with this energy.

2.2 SOLAR RADIATION

The Sun is a large sphere of diameter $D_s = 1.39 \times 10^6$ km. Because of nuclear fusion, temperature at the core of the Sun is around 10^7 K. The temperature at the outer passive layer of the Sun reaches to 5880 K so it becomes a source of radiation. Since the fluctuation at the surface temperature is not relatively high, hence it emits radiation with a relatively continuous spectral distribution.

Solar flux reaches Earth's surface at a maximum flux density of 1.0 kW/m^2 in the wavelength band of 0.3 μm and 2.5 μm. This range is known as short wave radiation.

Solar radiation is the energy emitted by Sun in the form of electromagnetic waves and hence solar radiation belongs to a particular region of electromagnetic waves. Electromagnetic wave spectrum is shown below to describe the wavelength of various waves of practical importance.

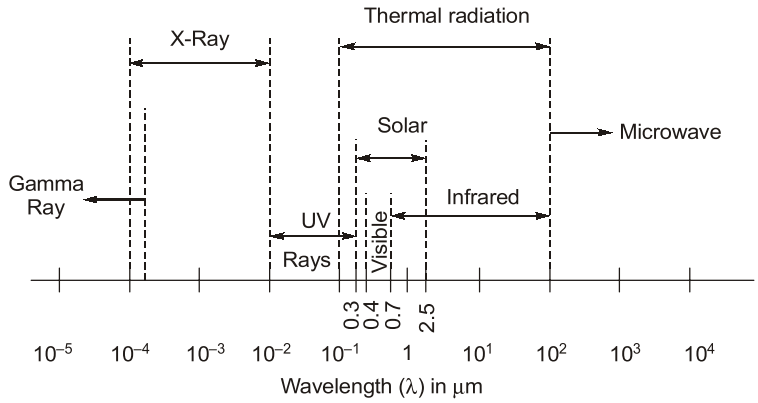


Figure: Spectrum of Electromagnetic waves

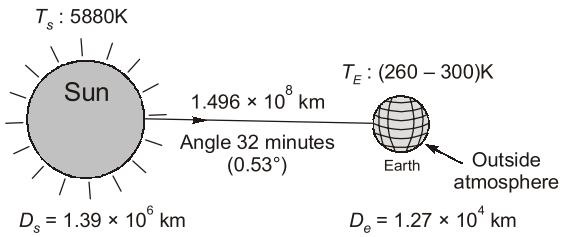
It can be seen from the spectrum of electromagnetic waves that the solar radiation covers entire range of visible radiation and some part of ultraviolet (UV) and infrared radiation (IR). The proportion of solar radiation received on Earth's surface for an incidence angle of 45° is shown in Table given below :

Table: Proportion of solar radiation

S.No.	Region	Wavelength (μm)	% Irradiance
1.	UV rays	(0.3 to 0.4)	~ 6.4%
2.	Visible	(0.4 to 0.7)	~ 48%
3.	Infrared	(0.7 to 2.3)	~ 45.6%

2.3 SOLAR RADIATION QUANTIFICATION

Sun being at higher temperature (5880 K) emits radiation in all possible directions. Temperature of Earth is around (260 - 300) K and it receives solar radiations. Because of very large size of Sun (Diameter $D_s \simeq 1.39 \times 10^6$ km) compared to Earth (Diameter $D_e \simeq 1.27 \times 10^4$ km), it subtends an angle 32 minutes i.e. 0.53° as the mean distance of Sun and Earth is 1.496×10^8 km.



Important points:

- Solar radiation incident on the outer atmosphere of the Earth is known as extraterrestrial radiation, I_{ext}.
- Solar radiation that reaches earth surface after passing through the Earth's atmosphere is known as Terrestrial radiation.

Basic components:

(i) Detector or sensor protected by glass dome.

(ii) Instrument body with adjustable screws, spirit level and a desiccant chamber.

(iii) Radiation shield to protect the instrument case from direct sunlight.

(iv) Electrical connector for the output signal.

2. **Pyrheliometer:**
   - It is used to measure direct (beam) radiations.
   - Sun tracking mechanism is required.
3. **Campbell-Stokes Sunshine Recorder :**
   - It is used to measure number of insolation hours.
   - For precise measurement, this instrument is installed several meters above the ground.
4. **Albedometer :**
   - It measures both global radiation and reflected radiation.
   - For precise measurement, this instrument is installed several meters above the ground.

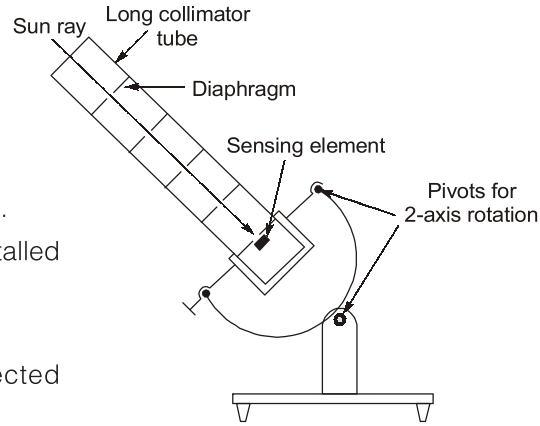


Figure: Pyrheliometer

EXAMPLE : 2.6

Albedometer is used for

(a) Measurement of both global radiation and reflected radiation.

(b) Measurement of isolation hours.

(c) Measurement of direct (beam) radiations.

(d) Measurement of global Solar radiations.

Solution: (a)

Pyranometer : Used to measure global and diffused solar radiation.

Pyrheliometer : Used to measure direct (beam) radiation.

Campbell-Stokes Sunshine Recorder : Used to measure number of insolation hours.

Albedometer : Used to measure both global and reflected radiation.

■■■■

OBJECTIVE BRAIN TEASERS

Q.1 Solar radiation covers

(a) entire spectrum of electromagnetic wave

(b) visible range of EM spectrum

(c) infrared (IR) range of EM spectrum

(d) some part of UV rays and IR rays along with full visible range.

Q.2 Solar constant is

(a) The wavelength at which emissive power of sun is maximum

(b) A distance between centre of sun and earth

(c) The rate at which solar energy is received from the Sun on a unit area perpendicular to the rays, at outer most part of atmosphere

(d) A universal constant value due to gravitational pull of the sun

Q.3 Extraterrestrial Solar radiation peaks in the region of EM spectrum

(a) Visible Range (b) Infrared Range

(c) UV range (d) None of the above

CONVENTIONAL BRAIN TEASERS

Q.1 In order to design Sun tracking mechanism, an engineer wants to calculate hour angle from 0830 to 1530 local apparent time. Find out the range of hour angle to help poor engineer.

Solution:

Hour angle is given by

$$\omega = 15(t_{zone} - 1200) + \omega_{eq.} + (\psi - \psi_{zone}) \quad \text{... (i)}$$

Since information required to calculate ω_{eq} and ψ, ψ_{zone} is missing and hence these terms can be neglected.

$\therefore$ Equation (i) reduces to

$$\omega = 15(t_{zone} - 1200)$$

For given data : $\omega_1 = 15(0830 - 1200) = 15(-3.5)$

$= -15 \times 3.5 = -52.5°$

Similarly $\omega_2 = 15(1530 - 1200) = 52.5°$

Hour angle varies in between (–52.5° to 52.5°)

Q.2 Determine local apparent time corresponding to 1530 h (IST) at Mumbai (19°07′ N, 72°51′E) on July 1. In India, standard time is based on 82.50°E. Also calculate hour angle for the given data.

Solution:

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

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

From the given data S.T. = 1530 h

S.T longitude, $(\psi_{zone}) = 82.50°$

Longitude of location, $(\psi_{local}) = 72°51' = 72.85°$

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

$$n = 31 + 28 + 31 + 30 + 31 + 30 + 1 = 182$$

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

Substituting this value into equation (2) :

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

$= -3.4618$ (minutes)

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

$LAT = 1530 - 4\,(82.50° - 72.85°) - 3.4615$

$= 1530 - 38.6 - 3.4618 \simeq 1448$ h

CHAPTER

3

Solar Thermal Energy Collection

3.1 INTRODUCTION

Solar thermal energy collection is a challenging task primarily because incident radiation energy is available in dilute form, at best, approximately 1100 W/m^2 flux is received without optical concentration. The other reason is, this energy is varying in nature and available over the wavelengths falling in the range of 0.3 μm to 3.0 μm.

The devices used to collect Solar thermal energy are known as Solar collectors or simply collectors. A Solar collector is a special kind of heat exchanger that transforms Solar radiant energy into heat. The design of Solar collector presents unique problem of low and variable energy fluxes. The fundamental working principles of a Solar collector are :

- Expose a dark surface to the solar radiation so that radiation is absorbed.
- Transfer a part of the absorbed radiation to the working fluid like air/water/refrigerant.

3.2 CLASSIFICATION OF SOLAR COLLECTORS

The overall view of classfication of solar collectors into categories and sub-categories as shown in figure below. The classification is based on the way they collect solar radiation.

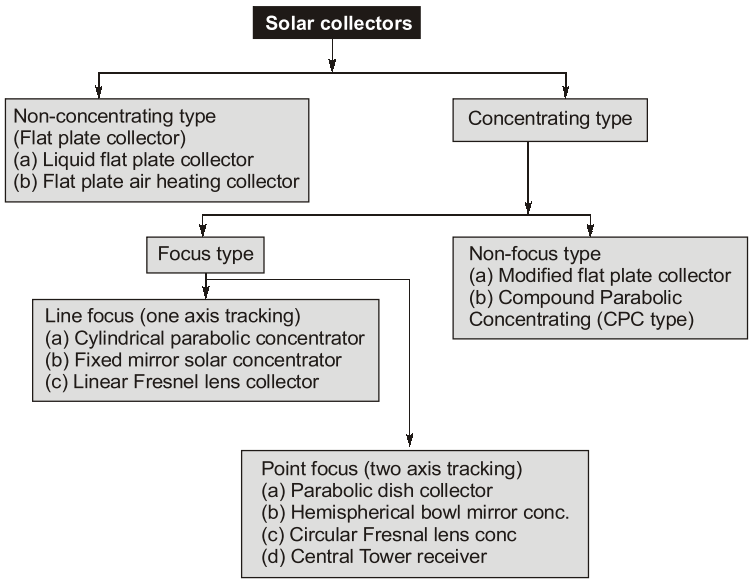


Figure : Types of solar collectors

3.3 FLAT PLATE COLLECTOR

A collector is said to be a flat plate collector when no optical concentration is done.

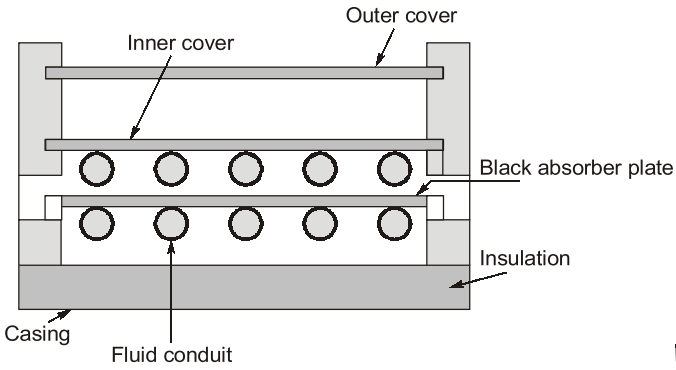


Figure: Cross Sectional View of a Flat Plate Collector

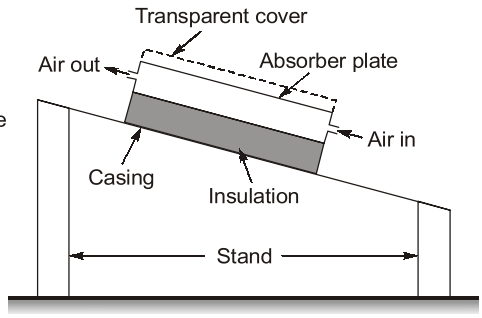


Figure: Air Heater

EXAMPLE : 3.1

Statement (I): In case of flat plate collector, convection losses are very high for high power generation.
Statement (II): Large area is required in flat plate collectors.

(a) Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are true but Statement (II) is not a correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

Solution: (a)

$$Q_{convection} \propto \text{Area}$$

So, convection losses will increase as area increases.

3.3.1 Key Components of a Flat Plate Collector

1. **Absorber Plate :** The objective of absorber plate is to absorb solar radiations falling upon it and to transfer a part of absorbed radiation to a liquid flowing through tubes. The energy transferred to the liquid is useful heat gain for the collector.
   The remaining part of the energy is lost to the surrounding by conduction and re-radiation from top cover surface(s), and by conduction from back and side edges.
   Selective coating is applied on the absorber plate to avoid re-radiation losses. The coating material has high absorptivity for short wave radiation and low emissivity for long wave radiation.
2. **Transparent cover :** The objective of the transparent cover is to allow solar radiation to reach the absorber plate and to minimize heat losses due to convection and re-radiation.
3. **Fluid Conduit (Liquid Tube) :** Liquid tube acts as a heat exchanger. It takes heat from absorber plate and transfers to the fluid flowing inside the tube. Thermal conductivity of fluid conduit (Liquid Tube) should be high.
4. **Insulation :** Collector is well insulated from backside and at both the ends, so that conduction losses can be controlled.
5. **Stand/casing :** Stand and casing provide structural rigidity to the whole system. It should be light in weight and economical.

3.9 ADVANTAGES AND DISADVANTAGES OF CONCENTRATING COLLECTORS OVER FLAT PLATE TYPE COLLECTORS

(a) Advantages:

- Less material is required due to reflecting surfaces.
- Higher temperature is obtained.
- Due to high temperature, can be used for electric power generation when not used for heating or cooling.
- Higher efficiency is obtained.

(b) Disadvantages:

- Only beam radiation component is collected.
- Costly orientation systems have to be used to track the sun.
- Maintenance is required to protect against dirt, weather, oxidation etc.
- Non-uniform flux on the absorber.
- Higher initial cost.

■■■■

OBJECTIVE BRAIN TEASERS

Q.1 The transparent cover of collector serves the purpose(s) of
(a) Avoiding heat loss due to convection
(b) Avoiding heat loss due to conduction and convection
(c) Avoiding heat loss due to convection and re-radiations
(d) Avoiding heat loss due to conduction, convection and re-radiation

Q.2 Tilt factor for a diffuse radiation for a vertical flat plate collector is
(a) 1 (b) zero
(c) 0.5 (d) 0.707

Q.3 A collector is inclined at an angle 20° to the horizontal. Find out tilt factor of diffused and reflected radiation if ground reflectivity is 0.2.
(a) 0.97, 0.006 (b) 0.03, 0.194
(c) 0.97, 0.194 (d) 0.03, 0.006

Q.4 Match **List-I** (Solar collectors) with **List-II** (Tracking) and select the correct answer using the codes given below the lists:

List-I

A. Circular Fresnel lens concentrator
B. Fixed mirror solar concentrator
C. Liquid flat plate collector

List-II

1. 1 Axis tracking
2. No tracking
3. 2 Axis tracking

Codes:

	A	B	C
(a)	1	3	2
(b)	3	1	2
(c)	2	1	3
(d)	3	2	1

Q.5 **Statement (I):** Glass material for transparent cover is preferred over plastic.
Statement (II): Plastic material for cover cannot withstand high stagnant temperature.
(a) Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are true but Statement (II) is not a correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

Q.6 Surface of absorber plate is coated by selective surfaces. Which of the following is used for this purpose?
(a) Black chrome (b) Nickel chrome
(c) Cermet (d) All of them

CONVENTIONAL BRAIN TEASERS

Q.1 A hotel industry intends to replace its existing electric water heating system with a solar water heating system. The requirement of hot water is around 6000 litre per day. The proposed solar collector area is around 120 m^2 and the average solar radiation falling can be considered as 700 W/m^2. If the collector efficiency is 60%, estimate the reduction in electricity bill of the hotel on yearly average basis. Consider cost of electricity as ₹8/kWh. Make suitable assumptions wherever required. Consider average value of length of the day as 12 hours. Also estimate temperature rise of water for given radiation and collector efficiency data. Assume Indian context. Assume electric geyser efficiency as 90%.

Solution:

Given : Hot water required = 6000 *l*/day, $A = 120\ m^2$, $I = 700\ W/m^2$, $\eta_c = 0.6$,

Cost = ₹8/kWh, Day length = 12 hour, $\eta_{geyser} = 0.9$

$$\text{Total heat collected per second} = \eta_c \times A \times I = 0.6 \times 120 \times 700$$

$$= 50.4\ kW$$

$$\text{Total heat collected in a day} = 50.4 \times 12 \times 3600 = 2177.28 \times 10^3\ kJ/day$$

$$= \frac{2177.28 \times 10^3}{3600} kWh/day = 604.8\ kWh/day$$

$$\text{Actual electricity consumption} = \frac{604.8}{0.9} = 672\ kWh/day$$

$\therefore$ Per day saving in electricity bill = $672 \times 8 =$ ₹5376/-

Yearly saving in electricity = $5376 \times 365 =$ ₹1962240/- per year Ans.

Now, heat received by solar collector = $mC_P\Delta T$

or $2177.28 \times 10^3 = 6000 \times 4.18 \times \Delta T$

$\therefore$ Temperature rise of water = $\frac{2177.28 \times 10^3}{6000 \times 4.18}$

$\Delta T = 86.81°C$

Q.2 Calculate the monthly average hourly radiation falling on a flat plate collector facing south ($\gamma = 0°$) with a slope of 15°, The following data is provided :

Location - Chennai (13°N)

Month - October

Time - 1100 – 1200 h

Monthly average hourly global radiations = 2408 kJ/m^2-h

Monthly average hourly diffused radiations = 1073 kJ/m^2-h

Ground reflectivity = 0.2

Glass transmissivity = 0.8

Absorber Plate Area = 2 m^2

Plate Absorptivity = 0.95

Also calculate total heat gain by collector and efficiency of collector if collector area is 2.4 m^2 and heat losses are 30% that of total heat gain.