PART-B ESSAY QUESTIONS WITH SOLUTIONS

1.1 Principle of Solar Radiation

1.1.1 Role and Potential of New and Renewable Source, The Solar Energy Option, Environmental Impact of Solar Power

Q30. What are the primary and secondary energy sources?

Answer : July-21, (ME), (R16), Q2(a)

Primary Energy Sources

The primary energy sources are defined as the energy sources that are either found or stored in the nature.

These sources provide a net supply of energy. The common primary energy sources include coal, oil, natural gas, biomass, nuclear substances like uranium, thermal energy stored in the earth's interior, etc.

The energy required to obtain these fuels is much less than the energy produced by them during combustion or nuclear reaction. The energy yield ratio is very high. Though, the primary fuels contribute significantly to the energy supply, their supply is limited. Thus, it is important use these fuels in small quantities.

Secondary Energy Sources

The secondary energy sources are derived from the primary energy sources. These sources do not produce net energy. The examples of secondary energy sources include the electricity generated by burning the coal or gas.

Q31. Differentiate between :

(a) **Primary and Secondary Sources**

(b) **Renewable and Non-Renewable Source**

(c) **Conventional and Non-Conventional.**

Answer :

(a)

	Primary Energy Source		Secondary Energy Source
1.	Primary energy sources are obtained from environment.	1.	Secondary energy sources are delivered from primary energy sources because they do not occur in nature.
2.	Ex : Fossil fuels, solar energy.	2.	Ex : Electrical energy obtained from burning the coal.

(b)

	Renewable Energy Source		Non-renewable Energy Source
1.	These energy sources are inexhaustable and are produced continuously in nature.	1.	These energy source are limited and are exhaustible.
2.	Ex : Wood, Wind energy, Biomass.	2.	Ex : Coal, Petroleum.

(c) **Conventional and Non-Conventional Energy Sources**

For answer refer Unit-I, Q5.

Q32. Explain the significance of energy consumption as a measure of prosperity?

Answer : July-21, (EEE), (R16), Q1(a)

Energy is one of the important parameter in any section of a country's economy. The per capita energy consumption determines the standard of living of people in a particular country. The rapid increase in population and improved standard of living leads to insufficient energy or energy crisis. If a graph is drawn between annual per capita income of various countries against per head energy consumption, then we observe that per capita energy consumption, is a measure of per capita income or in other words, prosperity of the nation depends on per capita energy consumption. The percapita energy consumption of a developing country like India is 150 kWh per year where as per capita energy consumption of a developed country like USA is 8000 kWh.

Though, USA has 7% of worlds population and India has 20% of worlds population, USA consumes 32% of total energy consumed in the world where as India consumes only 1% of total energy. Therefore, Now we can conclude saying that, human being must consume more and more energy for material prosperity.

Due to lack of energy in developing countries, the primary products like tea, jute, coffee, food, ores etc. are exported to other countries without processing to final products. Therefore, the full value of the resources are not benefited to people.

Q33. Describe briefly the world energy scenario.

OR

Explain in brief the world energy scenario along with the alternate energy strategies.

Answer : [July-21, (EEE), (R16), Q2(a) | Model Paper, Q2(a)]

World Energy Scenario

1. **Conventional Sources of Energy**

(i) **Fossil Fuels**

The main important source of energy are fossil fuels, that are obtained by the decomposition of organic matter under the earth, by bacterial action. Some of the examples of fossil fuels are coal, oil and natural gas. But, these fossil fuels lasts upto a limited period, i.e., for few decades.

(ii) **Hydro Resources**

These resources does not cause any pollution to the environment, but the capital investment is more. The generating capacity of these resources is about 627000 MW, which can generate 23% of total electric power produced all over the world.

(iii) **Nuclear Resources**

Uranium reserves are the example of nuclear resources and are very scarce. About 440 nuclear power plants are present all over the world, which are able to generate about 1/6 th of total electricity produced in the world.

2. **Non-conventional Sources of Energy**

(i) **Solar Energy**

The major source of power, which is widely used, is solar energy. It is commonly used in thermal and photovoltaic conversion systems. About 178 billion MW of solar energy is received by the earth continuously. This is 10000 times greater than the world's requirement.

(ii) **Wind Energy**

It is estimated that the power produced from wind turbines is about 1.6×10^5 MW. The power generating capacity of wind turbines that are installed all over the world is 47317 MW.

(iii) **Biomass Energy**

These resources include wood and forest wastes, algae from oceans and lakes, municipal and industrial wastes etc. Using biological methods, these biomass materials are transformed to obtain biofuels like methane, producer gas, ethanol, etc. The energy produced by biomass is estimated as 2×10^{21}J per year.

(iv) **Geothermal Energy**

The present power generating capacity of geothermal resources is about 7704 MW all over the world, while 16649 MW capacity is directly used as heat.

(v) **Ocean Tidal Energy**

Ocean tidal energy resources are capable of producing about 550 billion kW of energy per year.

(vi) **Ocean Wave Energy**

Its capacity is estimated as 20×10^5 MW.

(vii) **Ocean Thermal Energy Conversion**

The capacity of this resource is more than tidal or wave energy resources.

Q34. Briefly write a notes on Indian Energy Scenario.

Answer :

Indian Energy Scenario

In India, energy is highly produced as well as consumed. India produces energy of about 2.4% of the total annual energy production in the world and stands in eleventh place in highest energy producers of the world. While in consumption, India consumes energy of about 3.3% of the total annual energy consumption in the world and is ranked with sixth position among world's highest energy consumers. According to the report of 2007 data, India's annual per capita of electrical energy consumption is 702 kWh and that of the world's average is 2600 kWh.

Energy utilization of various sectors in India is given in the following table.

Sectors	Energy Consumption (in %)
Industries	49
Transportation	22
Agricultural	5
Residential (domestic)	10
Others	14

Energy production in India as per the data of June 30, 2008 is 144912 MW from different energy sources. The details are as follows;

Energy Source	Energy Produced (in MW)
Thermal sources	
(i) Coal	76648
(ii) Gas	14716
(iii) Diesel	1199
Nuclear source	4120
Hydro source	36033
Other renewable sources (except hydro source)	12194

Q35. Briefly explain the global and Indian energy scenario.

Answer: Sep.-20, (R16), Q1(b)

Global Energy Scenario

For answer refer Unit-I, Q33.

India Energy Scenario

For answer refer Unit-I, Q34.

Q36. Explain in brief the need for exploiting renewable energy sources.

April-18, (ME), (R13), Q3(a)

OR

State the need of using renewable energy sources.

Answer :

The demand of energy is growing owing to rapid urbanization, increased population growth and improved standard of living. Electricity is predominantly used for different household activities such as air conditioning, refrigeration, water heating, cooking, lighting, grinding, entertainment and washing. However, the main problem is that the ability to produce energy has not kept up with the growing urban areas. Additionally, the problems associated with the development of conventional sources of energy has made the environment conscious population to shift their focus to renewable energy sources.

Q37. Why the renewable energy technologies are more attractive than the conventional energy technologies.

Answer :

The renewable energy technologies are more attractive than the conventional energy technologies due to following reasons.

1. The renewable energy technologies are adequate to accommodate the huge demand, and deliver the quality energy that is required for a particular operation. Hence, the use of premium fuels or electricity to obtain low grade forms of energy such as hot water is significantly reduced.
2. The transmission costs are reduced to a great extent, since these plants can be built on, or near to the site where the energy is used.
3. The renewable energy plants can be built in less time unlike large power stations, which have long lead times.
4. Due to the diversity of renewable energy sources are available, the flexibility and the security of supply is high.
5. The environmental and physical risks associated with the construction and operation of renewable energy technologies is less than that of conventional plants.

Q38. Classify the renewable energy sources. What are the factors affecting energy resource development?

Answer : July-21, (ME), (R16), Q1(a)

Classification of Energy Resources

For answer refer Unit-I, Q3.

Factors Affecting Energy Resource Development

The following factors affect the energy resource development.

1. Fuel or energy substitution
2. Energy density
3. Power density
4. Energy distribution in any particular area
5. Intermittency of energy resource.

Q39. Classify renewable energy sources? Explain in brief the need of these energy sources with special reference to India.

Answer : June-18, (R13), Q3(a)

Classification of Renewable Energy Sources

For answer refer Unit-I, Q3.

Need for Renewable Energy Resources in India

The economic development of any country mainly depends on its energy production and utilization. At present, India is the planet's third-largest energy consuming country. Because of continuous economic development and increased use of electricity by the growing population, India, is about to experience the largest increase in energy demand than any other country in the world over the next 20 years.

The energy consumption of India has more than doubled since the year 2000. Over 80% of India's energy needs are met by three fuels; coal, oil and solid biomass. Coal has major contribution in the expansion of electricity generation and industry, Oil consumption and imports have grown rapidly as the use of private or individual vehicles are increased significantly. Though the use of Biomass (primarily fuel-wood) for energy production is continuously reducing, still it is widely used as a cooking fuel. The government is expanding the coverage of LPG in rural areas, still it is widely used as a cooking fuel. The government is expanding the coverage of LPG in rural areas, but still 660 million Indian have not fully switched to modern, clean cooking fuels or technologies.

India faces a range of energy security challenges in near future. Based on today's policy settings, India's combined import bill for fossil fuels is estimated to become triple over the next two decades, oil being the largest component. The gap between the production of oil and gas, and consumption levels in India continues to increase. The net dependence on imported oil rises above 90% up by 2040, from 75% today. If India continues to rely on imported fuels, there may be a chance of raises in price cycles and volatility, and possible disruptions to supply. India is the third-largest global emitter of CO_2, despite low per capita CO_2 emissions.

India should be transitioned from the conventional energy to the clean and renewable energy for lasting prosperity and greater energy security. India has a greater advantage of tapping the solar energy as it receives sunshine most of the year, and it also has the greater potential in hydropower sector.

Q40. "Renewable energy options will mitigate global warming". Justify the statement in brief.

Answer:

Sep.-20, (R16), Q1(a)

Emission of Green House gases contribute to Global Warming. In order to mitigate Global Warming, it is required to develop advanced technologies for power generation using renewable energy source more vigorously. Generating power from renewable energy sources like solar, wind, geothermal energies emits relatively very less green house gases when compared to power generation from fossil fuels.

Major cause of Global Warming is the emission of green house gases. Among green house gases CO_2 and methane contributes for 90% of global warming. The main source of these emissions is the fossil fuel burning for generation of electricity, transportation, etc which accounted for 80% of world's energy. Therefore usage of renewable sources for electricity generation and transportation can reduce the emission of green house gases to a larger extent. Solar and Wind Energy are becoming economical and affordable with technological advancements and replacing fossil fuels for electricity generation accounting to about 75% of all the new installations in 2019.

For transportation, energy sources such as electricity, bio-ethanol, biodiesel are replacing fossil fuels, thereby reducing the Green House gas emissions.

Wind and solar power are expected to generate around 50% of the worlds energy needs by 2050, where as 20% in 2020, mainly replacing coal thereby reducing emissions. Geothermal, bio mass are also contributing to a smaller extent to replace the conventional sources.

Thus, Renewable energy Sources replacing conventional/ Traditional Sources for energy generation reduces the emission of Green House Gases resulting in reduction of the Global Warming.

Q41. Give the availability and relative merits of different non-conventional energy sources.

OR

List various non-conventional energy resources. Give their availability, relative merits and their classification.

April-14, (R09), Q1(a)

Answer :

The availability and merits of different non-conventional energy sources are explained as follows,

1. **Solar Energy**

Availability

(i) Solar energy is cheap, clean and abundantly available in nature.

(ii) It gives 10000 times more power, than required.

(iii) The available power is 178 billion MW.

(iv) In India, 48% of power is generated from solar energy.

Merits

(i) It does not produce wastes, thus keeps the environment clean.

(ii) It requires minimum maintenance.

(iii) It is a readily available non-conventional source of energy.

(iv) It is reliable.

2. **Wind Energy**

Availability

(i) It is available in some parts of Central India and Western Rajasthan.

(ii) The wind pumps employed for generating wind energy around the world is about 0.7 million.

(iii) Its potential ranges from 20000 MW to 25000 MW.

Merits

(i) It is clean, abundant and cheap and exist as long as sun exists.

(ii) It is permanent and inexhaustible source of fuel.

(iii) It does not produce toxic wastes or greenhouse gases, which contribute to global warming.

(iv) It is pollution free energy.

3. **Biomass Energy**

Availability

(i) It is derived from wood, animal and agricultural residues, etc.

(ii) Biogas plants are mostly found in china.

(iii) The power available is upto 1 MW.

(iv) It is mostly used in villages.

Merits

(i) The wastes may be utilized to produce energy.

(ii) The fuel used is less expensive.

(iii) This energy saves firewood, leading to conservation of forest.

4. **Geothermal Energy**

Availability

(i) It is obtained from thermal energy, which is stored beneath the surface of earth.

(ii) It is available in the form of hot water or steam.

Merits

(i) It does not contribute to pollution and greenhouse effect.

(ii) No fuel is needed to generate electricity.

(iii) The power stations do not occupy much space, hence, no impact on environment.

5. **Ocean Tidal Energy**

Availability

(i) It is available in India, China, Europe, Argentina, USA, etc.

(ii) The power available in Canada, Scotland is 20 MW and in Russia, Cuba is 400 KW.

Merits

(i) It is pollution free, as no greenhouse gases are produced.

(ii) It does not need fuel.

(iii) The long stretch of coastlines can be protected from high storm tides.

6. **Ocean Wave Energy**

Availability

(i) It is available in Portugal, Scotland, England, Japan, etc.

(ii) The wave power generation is approximately 50000 MW.

Merits

(i) Low operation and maintenance cost.

(ii) No fuel is needed, as the energy of waves occur naturally.

Q42. Differentiate renewable and non renewable energy sources and state their relative merits and demerits.

Answer: Sep.-20, (R16), Q2(a)

Differences between Renewable and Non-Renewable Energy Sources

For answer refer Unit-I, Q5.

Merits and De-merits of renewable Energy Sources

1. Renewable energy is an inexhaustible resource available in considerable quantities to all developing nations. It enables economic improvement and develops a scope for local employment.

2. Application of renewable energy in rural areas is more economic and efficient, as cost of transmitting electrical power or transporting conventional fuels is reduced to a great extent.

3. There is a provision for development of conversion technology.

4. It has wide range of applications.

Limitations of Renewable Energy Sources

1. Inappropriate documentation and evaluation of past experience may lead to difficulties in project.

2. Renewable energy systems may become unsuccessful if financed by improper sources or weak institutions.

3. Lack of energy planning may lead to undesired energy consumption.

4. Technical or economic problems caused in energy systems increases the cost of conversion.

5. The information available to coordinate energy system activities from past projects is very less.

Merits and De-merits of Non-Renewable Energy Sources

Merits

1. They possess high energy content

2. Cost of production is lower

3. Energy tapping is comparatively easier due to extensive research and technological advancements.

De-merits

1. These are not eco-friendly, because these are the main cause of air and water pollution.

2. These resources are limited and are depleting rapidly.

Q43. Discuss briefly the prospects of non-conventional energy sources in India.

July-21, (ME), (R16), Q2(b)

OR

Explain the potential of renewable energy sources in India. Dec.-20, (R16), Q1

OR

Discuss on potential of renewable energy sources in India. July-19, (R15), Q3(b)

OR

Discuss on potential of renewable energy sources with reference to India.

Answer : April-18, (ME), (R13), Q2(a)

India ranks third place in production of electricity through renewable energy sources. About 38% of total power in India is produced from renewable energy sources i.e., 136 GW of power. The potential of various renewable energy sources in India is as follows.

In India, there is a high potential for generation of renewable energy from various sources-wind, solar, biomass, small hydro and cogeneration bagasse. The total potential of renewable energy power generation in the country is estimated at 1,097,456 MW as on 31st March 2020. Of this total potential, solar power potential is about 748990 MW (68.25%), wind power potential is about 302251 MW (27.54%) at a 100 m hub height, small-hydro power (SHP) potential is about 21134 MW (1.93%), Biomass power potential is about 17,536 MW (1.60%), and about 5000 MW (0.46%) from bagasse based cogeneration in sugar mills and 2554 MW (0.23%) from waste to energy. The potential of renewable energy sources in Indian is shown in below figure.

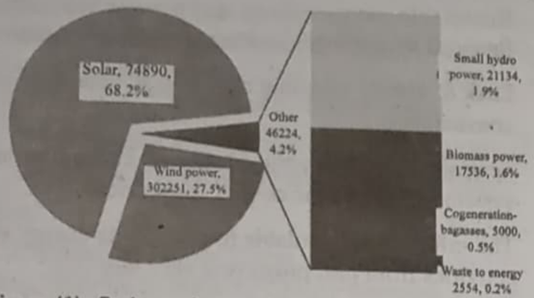


Figure (1) : Estimated potential of Renewable power as on 31-03-2020

The geographic distribution of the potential of renewable energy power :

As on 31st March, 2020, Rajasthan has the highest share of about 15% (162223 MW). Gujarat with 11% share (122086 MW) is in the second place. With a 10% share, both Maharashtra (113925 MW) and Jammu & Kashmir (112800 MW) will take the next place, mainly on account of solar power. The share of wind power is the highest in Gujarat. The geographic distribution of the potential of renewable energy power is shown in the below figure.

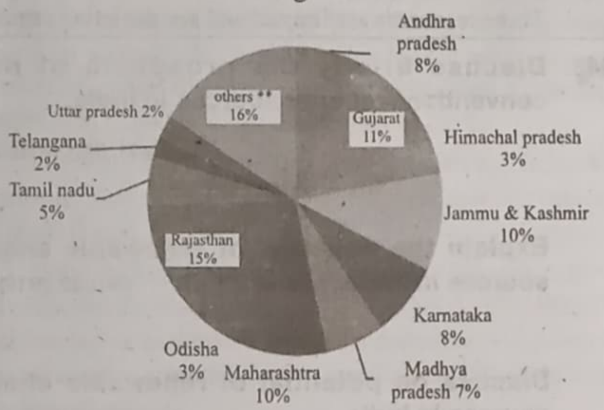


Figure (2) : Geographic distribution of the potential of renewable energy power as on 31-03-2020

Q44. Explain the global potential of renewable energy sources.

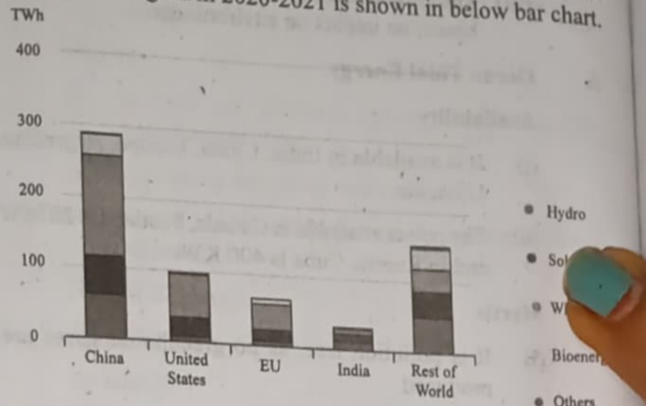
Answer : July-21 (EEE), (R16), Q2(b)

The use of renewable energy is increased by 3% in 2020 as demand for all other fuels is decreased. The share of renewable sources in global electricity generation is jumped to 29% in 2020, up from 27% in 2019. The wind power and solar PV cumulatively added 256 GW of capacity in 2020, an increase of nearly 10 percent in total installed renewable power capacity.

Globally, about 11.2% of the energy consumed for heating, power generation and transportation came from modern renewables in 2019 (i.e., biomass, geothermal, solar, hydro, wind, and biofuels).

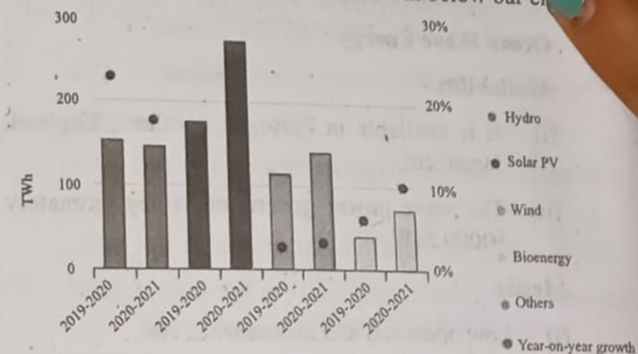
In 2021, renewable electricity generation is set to expand by more than 8% to reach 8300 TWh. Solar PV and wind are set to contribute two-thirds of renewables growth. China accounts for almost half of the global increase in renewable electricity in 2021, followed by the United States, the European Union and India.

Renewable electricity generation increase by technology, country and region in 2020-2021 is shown in below bar chart.



Chart

Renewable electricity generation increase by te... in 2019-2020 and 2020-2021 is shown in below bar c...



Chart

Q45. Discuss the global and Indian renewable energy usage and availability.

Answer : July-21 (ME), (R16), Q1(b)

Indian Renewable Energy Usage & Availability

For answer refer Unit-I, Q43.

Global Renewable Energy Usage & Availability

For answer refer Unit-I, Q44.

Q46. Highlight the energy potential associated with any three types of renewable energy resources with examples.

Answer : May-19, (R15), Q2(a)

Energy Potential Renewable Energy Resources

For answer refer Unit-I, Q43.

Examples

Renewable Energy Resource	Examples / Applications
Solar	Solar water heater, solar cookers, solar cells and solar thermal power stations
Wind	Wind turbine power stations
Hydro	Small to large scale Hydroelectric power plants
Biomass	High temperature cooking, smelting, etc.
Geothermal	Low temperature heat is used for bathing, space and water heating

Q47. How do you plan for adopting renewable energy generation system in your college? What are the factors that influence the selection of renewable source?

May-17, (EEE), (R13), Q11

Answer :

Growing demand for energy requirement has lead to the exhaust of fossil fuels. Use of these fuels results in atmospheric pollution. Hence, alternative methods for producing energy must be adopted.

Some of the methods are,

1. Solar energy source
2. Hydro energy source
3. Wind energy source
4. Nuclear energy source
5. Geothermal energy source
6. Ocean wave energy
7. Biomass energy
8. Ocean thermal energy

One of the best techniques that can be adopted as renewable energy source system in a college is use of solar energy. use of conventional electricity is highly expensive. Hence, the maintenance cost of the college is increased. In a college, consumption of energy is not only for the electrical equipment, but also for the large lab equipment such as large electrical machines that consumes huge electricity. Supply of conventional electricity to these heavy machines is not possible all the time. Some times, there may be power cut, due to which there will be delay in activities that undergo in a college. Hence, use of solar energy as the source of electricity production can reduce the maintenance cost of the college. To utilize solar energy, solar panels can be employed for the generation of electricity from solar radiation.

The wastes developed in the college surroundings such as in canteens and other wastes can be used for the production of electricity through bio-energy. The availability of bio-wastes in a college is less. Hence, only a small amount of electricity is produced by this method.

Wind mills can also be used, but due to fluctuation of wind, continuous production of electricity is not possible. Use of other sources of renewable energy is bit complicated such as geothermal energy source and some are impossible such as Hydro, nuclear, ocean thermal, ocean-wave energy source.

The factors that influences the selection of renewable sources in a college are,

1. Availability of large space for the installation of solar panels.
2. Production of electricity is highly dependent on the climate.
3. Cost for installation of solar power plant in high.
4. Availability of biomass.

Q48. What is the role of solar energy utilization in future power crisis? Explain.

Answer :

May-17, (EEE), (R13), Q1(a)

Solar energy is an important form of non-conventional sources of energy. The scope for technological advancement has led to the development of photovoltaic cells, which are efficient and economic.

The high rate of consumption of fossil fuels like coal, natural gas, oil, etc., necessitates the use of non-conventional source of energy. Thus, it is observed that, by the end of 21st century, the fossil fuels get exhausted. Therefore, in order to conserve fossil fuels, the non-conventional sources of energy such as solar energy must be used as an alternative source.

The earth receives abundant solar radiation particularly during summer period, hence, it can be tapped, stored and utilized for various applications.

As population increases, the demand for energy increases. In the present time, it is noted that, a big difference occurs between the supply of power and demand. Hence non-conventional sources of energy must be given much significance, which can fulfill the future power demand.

The photovoltaic cells or solar cells convert solar power directly into electrical power. This power can be stored and utilized for multiple purposes.

The research and development on solar thermal power plants of high capacity is in progress and is expected to become practical in the near future. Therefore, considerable power can be added to the grid.

Q49. List the advantages, disadvantages and applications of solar thermal energy.

Answer :

May-15, (R09), Q2(a)

Advantages of Solar Thermal Energy

1. It is clean, cheap and abundantly available in nature.
2. It does not cause pollution and hence, it is eco-friendly.
3. This energy source can by reused.
4. It decreases the emission of green house gases.

Disadvantages of Solar Thermal Energy

1. The solar plants require large land area. Thus, the capital cost is high.
2. Solar thermal energy is dependent on climate and therefore, the availability of sunshine is inconsistent.
3. A tracking mechanism is required, since the position of the sun always changes.
4. The solar energy needs to be stored for continuous use.

Applications of Solar Thermal Energy

For answer refer Unit-I, Q7.

Q50. What are the environmental impacts of solar energy?

Answer :

Environmental Impact of Solar Power

1. Since the solar plants require large area of land, the cost incurred in land grabbing is high in populated areas. The land cannot be reclaimed till the plant is decommissioned.
2. Due to careless disposal of heat transfer fluids (such as glycol nitrates and sulphates, CFCs and aromatic alcohols) may cause health hazards in public.
3. Presence of arsenic and cadmium in solar photovoltaic modules, may pose disposal problems.
4. Solar reflectors cause hazards related to eye sight.
5. The solar power generator is equipped with various accessories such as battery banks with inverter, back-up diesel generator. etc. Thus, the total system may contains several pollutants.
6. The solar thermal collectors and roof top photovoltaic (PV) systems may reduce the exposure of people to day light due to changes in albedo.

1.1.2 Physics of the Sun, The Solar Constant, Extraterrestrial and Terrestrial Solar

Q51. Briefly explain the physics of the sun.

Answer :

The sun is a hydrodynamic spherical body, which comprises of extremely hot ionized gases (also called plasma) and generates energy continuously by the process of thermonuclear fusion. The energy is produced in the interior of the sun by fusion of hydrogen to helium. The fusion reaction is as follows,

$$4({}^{1}H^{1}) \rightarrow {}_{2}He^{4} + 26.3\text{ MeV}$$

The temperature of the interior of the sun is estimated to be in the range of 8×10^6 K to 40×10^6 K.

The energy from the sun is radiated on to the earth in the form electromagnetic waves in following three spectral regions.

Spectral region	%of Total Energy	Wave Length
Ultraviolet	6.4%	$\lambda < 0.38$ μm
Visible	48%	0.38 μm $< 1 < 0.78$ μm
Infrared	48%	$\lambda > 0.78$ μm

Since the distance between the sun and the earth is very large, i.e., about 1.495×10^8 km, the beam radiation received by the earth from the sun is almost parallel (i.e., the solar rays subtend an angle of only 32 minutes on the earth.)

Q52. How is solar radiation reaching the earth?

May-19, (R15), Q1(a)

OR

Discuss about effects and interactions occurring as extraterrestrial solar radiation is incident upon the Atmosphere.

May-17, (EEE), (R13), Q3(a)

OR

What are the reasons for variation in solar radiation reaching the earth and that received outside the earth atmosphere?

[June-18, (R13), Q2(a) | May-17, (ME), (R13), Q2(a)]

OR

What is terrestrial solar radiation?

Answer : Model Paper, Q3(a)

Terrestrial solar radiation is defined as the intensity of sun's radiation received on the earth surface. If is approximately equal to the 70% of the extra terrestrial radiation.

When the solar radiation pass through the earth's atmosphere, it is subjected to scattering and atmospheric absorption. Some amount of scattered radiation is reflected back into the space. The scattering of radiation occurs due to air molecules, dust particles and water droplets present in the atmosphere, which cause attenuation of radiation. The ozone absorbs the short wave ultraviolet rays, and CO_2 and water vapours absorb long wave infrared rays. Because of these reasons, always there is a variation in solar radiation reaching the earth and that received outside the earth atmosphere. The below figure illustrates the detailed mechanism of terrestrial solar radiation.

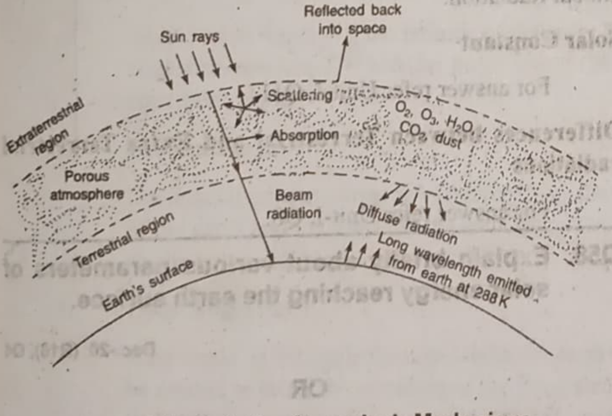


Figure :Solar Radiation Atmospheric Mechanisms

Q53. Discuss briefly about spectral distribution of extraterrestrial solar irradiance.

May-17, (EEE), (R13), Q2(b)

OR

Explain briefly about extraterrestrial radiation?

Answer :

Extraterrestrial radiation is defined as the intensity of sun's radiation outside the earth's atmosphere.

It is the "measure of solar radiation that would be received in the absence of atmosphere".

The distance between the earth and the sun changes throughout the year due to the elliptical motion of the earth. In the summer, the earth is closest to the sun and in the winter, the earth is farthest away from the sun. Thus, the extraterrestrial flux also varies according to the variations in the distance between the sun and the earth. The intensity of solar radiation (I) reaching the earth varies approximately in sinusoidal manner, and is calculated by the following equation.

$$\frac{I}{I_{sc}} = 1 + 0.033 \cos \frac{360(n-2)}{365}$$

$$\simeq 1 + 0.033 \cos \frac{360 \times n}{365}$$

Where,

I_{sc} – Solar constant

n – Day of the year counted from the first day of January.

A typical spectral distribution of extraterrestrial radiation is schematically shown in below figure.

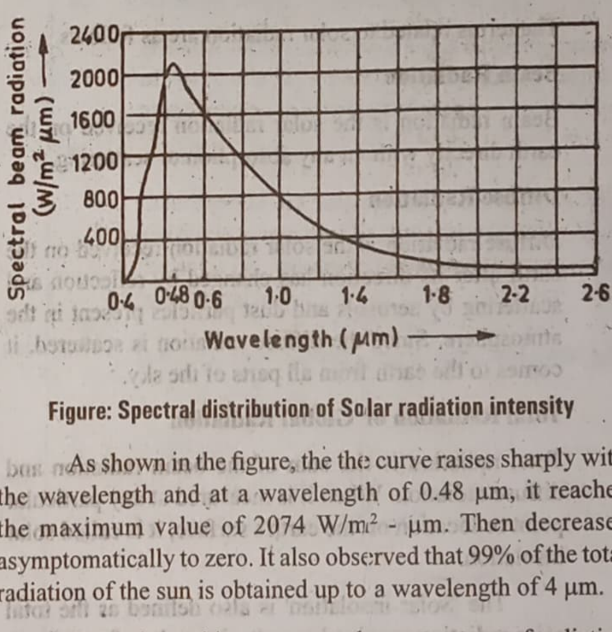


Figure: Spectral distribution of Solar radiation intensity

As shown in the figure, the the curve raises sharply with the wavelength and at a wavelength of 0.48 μm, it reaches the maximum value of 2074 W/m² - μm. Then decreases asymptomatically to zero. It also observed that 99% of the total radiation of the sun is obtained up to a wavelength of 4 μm.

The below table represents the percentage of radiation obtained at various ranges of wavelength.

Wavelength (μm)	Approximate energy (W/m²)	Approximate percentage of total energy
0 – 0.38	95	7%
0.38 – 0.78	640	47.3%
0.78 – 4.0	618	45.7%

Q54. What is Solar constant and Explain terrestrial and extra terrestrial solar radiation?

Answer : June-18, (R13), Q3(b)

Solar Constant

For answer refer Unit-I, Q11.

Terrestrial Solar Radiation

For answer refer Unit-I, Q52.

Extra Terrestrial Solar Radiation

For answer refer Unit-I, Q53.

Q55. Define solar constant. What are the reasons for variation in solar radiation reaching the earth and that received outside the earth atmosphere?

Answer: Sep.-20, (R16), Q3(a)

Solar Constant

For answer refer Unit-I, Q11.

Reasons for Variation in Solar Radiation Reaching the Earth's Surface and Outside the Earth's Atmosphere

For answer refer Unit-I, Q52.

Q56. Explain about the terms related to solar radiation reaching the earth surface.

Answer :

The terms related to solar radiation are as follows,

1. **Beam Radiation**

Beam radiation is the solar radiation received on the earth directly without any absorption or scattering.

2. **Diffuse Radiation**

Diffuse radiation is the solar radiation received on the earth after its direction has changed by reflection and scattering by aerosols and dust particles present in the atmosphere. Since the diffuse radiation is scattered, it comes to the earth from all parts of the sky.

3. **Total Radiation or Global Radiation**

Total radiation is the sum of the beam radiation and diffuse radiation. When it is measured at any particular point or location on the earth's surface, it is called solar insolation.

The 'Solar insolation' is also defined as the total solar radiation received on a horizontal surface of unit area in unit times.

4. **Sun at zenith**

'Sun at zenith' is the position of the sun directly overhead.

5, **Air mass (m)**

Air mass is the path length of beam radiation through the atmosphere if the vertical path at sea level is assumed to be unity.

Air mass is the ratio of the path length of beam radiation through the atmosphere, to the path length when the sun is at zenith.

The air mass (m) at various zenith angles is given as,

1. $m = 1$, if the sun is at zenith or directly overhead
2. $m = 2$, if zenith angle (θ_z) is $60°$
3. $m = 0$, just above the earth's surface
4. $m = \sec \theta_z$, if $m > 3$.

Where, θ_z is the angle subtend by the zenith and the line of sight to the sun.

5. **Irradiance**

Irradiance is defined as rate of incident energy per unit area of a surface.

6. **Albedo**

The earth reflects back approximately 30% of the total solar radiant energy to the space by reflection from clouds, by scattering and by reflection at the earth's surface. This is known as the albedo of the earth's atmosphere system.

Q57 . Define beam, diffused and global radiation. Define what is Solar constant and Differentiate Extra terrestrial and terrestrial radiation.

Answer: Sep.-20, (R16), Q4(a)

Beam Radiation

For answer refer Unit-I, Q56, Topic: Beam Radiation.

Diffuse Radiation

For answer refer Unit-I, Q56, Topic: Diffuse Radiation.

Global Radiation

For answer refer Unit-I, Q56, Topic: Total Radiation or Global Radiation.

Solar Constant

For answer refer Unit-I, Q11.

Differences between Terrestrial and Extra Terrestrial radiations

For answer refer Unit-I, Q8.

Q58. Explain briefly about various parameters of solar energy reaching the earth surface.

Dec.-20, (R16), Q4

OR

Explain about different parameters that describe the amount of solar energy reaching the earth's surface.

July-19, (R15), Q2(a)

OR

Explain briefly about the 'Solar radiation geometry'.

Answer :

The following angles are useful in the solar radiation analysis.

1. Latitude of location (ϕ_l)
2. Declination (δ)
3. Hour angle (ω)
4. Solar Azimuth angle (γ_s)
5. Altitude angle (α)
6. Zenith angle (θ_z)
7. Slope (s)
8. Surface Azimuth angle (γ)

1. **Latitude of Location or Latitude (ϕ_l)**

Latitude of a location or point is the angle between the line joining the location to the centre of the earth and the projection of this line on the equatorial plane. By convention, the latitude for northern hemisphere is measured as positive.

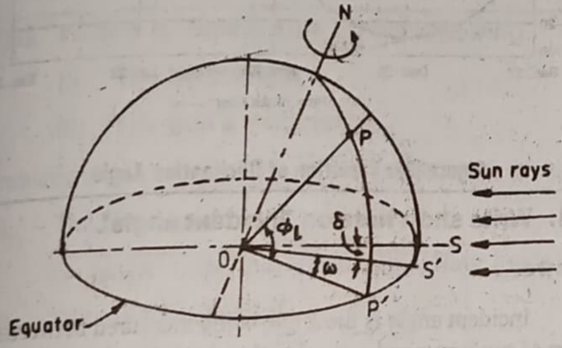


Figure (1) : Latitude ϕ_l, hour angle ω, and sun's declination δ

As shown in figure (1), the latitude of the point 'P' is the angle between line $\overline{OP}$ and the projection of $\overline{OP}$ on the equatorial plane

2. **Declination (δ)**

Declination is the angle made by a line joining the centres of the earth and the sun with the projection of this line on the equatorial plane of the earth.

3. **Hour Angle (ω)**

Hour angle is the angle through which the earth should be rotated to bring the meridian of the point directly in line with the sun rays It is equivalent to 15° per hour.

As shown in figure (1), the angle between the projection of $\overline{OP}$ and the projection of a line joining the centres of the sun and the earth.

Since the hour angle is measured from noon, based ion the local apparent time, it will be positive in the morning and negative in the afternoon.

Mathematically, it is expressed as, $\omega = 15(12 - LST)$

4. **Solar Azimuth Angle (γ_s)**

Solar azimuth angle is defined as the solar angle in degrees along the horizontal east or west of north.

(or)

It is the horizontal angle measured from north to the horizontal projection of the sun's rays.

This angle is considered to be positive if the sun's rays are west of south and negative if the sun's rays are east of south in the northern hemisphere.

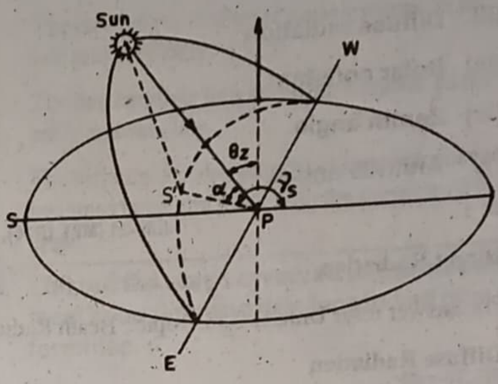


Figure (2) : Sun's Zenith, Altitude and Azimuth Angles

5. **Altitude Angle or Solar Altitude (α)**

Altitude angle is a vertical angle between the projection of the sun's rays passing through the point and its projection on the horizontal plane.

6. **Zenith Angle (θ_z)**

Zenith angle is a vertical angle between the sun's rays and a line perpendicular to the horizontal plane through the point i.e., the angle between the beam of sun's rays and the vertical.

It is the complementary angle of the altitude angle. i.e.,

$$\theta_z = \frac{\pi}{2} - \alpha$$

7. **Slope (β)**

Slope is the angle made by the plane surface with the horizontal surface as shown in below figure.

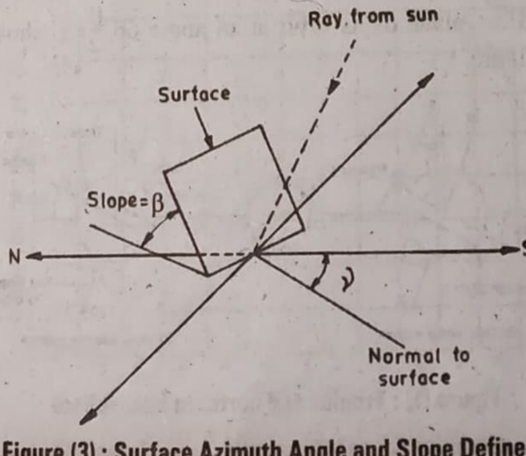


Figure (3) : Surface Azimuth Angle and Slope Defined

It is considered to be positive, if the surface is sloping towards the south and negative if the surface is sloping towards the north.

8. **Surface Azimuth Angle (γ)**

Surface azimuth angle is the angle of deviation of the normal to the surface from the local meridian, the zero point being south, east positive and west negative.

Q59. Define :

(i) Direct radiation

(ii) Diffuse radiation

(iii) Solar constant

(iv) Zenith angle

(v) Altitude angle.

Answer : July-21 (ME), (R16), Q3(a)

(i) **Direct Radiation**

For answer refer Unit-1, Q56, Topic : Beam Radiation.

(ii) **Diffuse Radiation**

For answer refer Unit-1, Q56, Topic : Diffuse Radiation.

(iii) **Solar Constant**

For answer refer Unit-1, Q11.

(iv) **Zenith Angle**

For answer refer Unit-1, Q58, Topic : Zenith Angle (θ_z)

(v) **Altitude Angle**

For answer refer Unit-1, Q58, Topic : Altitude Angle or Solar Angle (α).

Q60. Discuss briefly about the declination angle.

Answer :

Declination is the angle made by a line joining the centres of the earth and the sun with the projection of this line on the equatorial plane of the earth.

The declination occurs, since the axis of the earth is inclined the plane of its orbit at an angle $66\frac{1}{2}^\circ$ as shown in below figure.

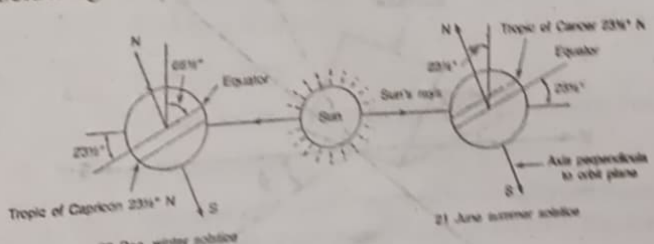


Figure (1) : Tropics and northern hemisphere

The declination angle varies from maximum to minimum values.

Maximum Value : +23.45° on June 21.

Minimum Value : –23.45° on December 22.

It is zero on two equinox days, i.e., on march 22 and September 22.

The approximate equation for declination angle is given by copper.

i.e., $\delta(\text{in degrees}) = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$

Where,

n – Total number of days counted from first January to the data of calculation.

The variation of declination angle in a year is shown in below figure.

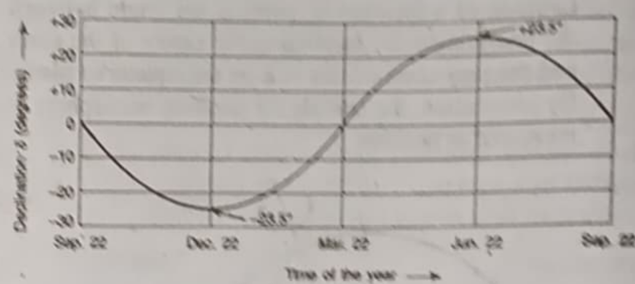


Figure (2) : Variation of Declination Angle

Q61. Write short note on 'Incident angle'.

Answer :

Incident angle is the angle being measured between the beam of sun's rays and normal to the plane. It is denoted by 'θ'. It depends on the position of sun and sky.

The general equation for '$\cos\theta$' is given by,

$$\cos\theta = \sin\phi_l(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) + \cos\phi_l(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma.\sin\omega\sin\beta$$

Where,

ϕ_l = Angle of latitude

ω – Hour angle

δ – Angle of declination

γ – Surface azimuth angle

β – Tilt angle or angle of slope.

'$\cos\theta$' for different cases is given as follow,

1. **For vertical surface**

For this case, slop angle, $\beta = 0$

$$\therefore \cos\theta = \sin\phi_l\cos\gamma\cos\omega - \cos\phi_l\sin\delta\cos\gamma + \cos\delta\sin\gamma\sin\omega.$$

2. **For Horizontal Surface**

For this case, $\beta = 0°$ and $\theta = \theta_z$ (zenith angle)

$\therefore \cos\theta = \cos\theta_z = \sin\phi_l \sin\delta + \cos\phi_l \cos\delta \cos\omega$

And $\cos\theta = \cos\theta_z = \sin\alpha \quad \left(\because \theta_z = \frac{\pi}{2} - \alpha\right)$

3. **Surface Facing South**

For this case, $\gamma = 0$

$$\therefore \quad \cos\theta = \sin\phi_l(\sin\delta\cos\beta + \cos\delta\cos\omega\sin\omega) + \cos\phi_l(\cos\delta\cos\omega\cos\beta - \sin\delta\sin\beta)$$

$$= \sin\delta\sin(\phi_l - \beta) + \cos\delta\cos(\phi_l - \beta)$$

4. **Vertical Surface Facing South**

For this case, $\beta = 0$ and $\gamma = 0$

$$\therefore \quad \cos\theta = \sin\phi_l\cos\delta\cos\omega - \cos\phi_l\sin\delta$$

In terms of θ_z,

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\,\text{co}(\gamma_s - \gamma)$$

$$\cos\gamma_s = \frac{(\cos\theta_z\sin\phi - \sin\delta)}{\sin\theta_z - \cos\phi}$$

Q62. Write a technical note on the following

(i) The hour angle

(ii) The Sun's declination.

Answer : May-17, (EEE), (R13), Q2(a)

(i) **The Hour Angle**

For answer refer Unit-I, Q58, Topic: Hour Angle (ω).

(ii) **The sun's Declination**

For answer refer Unit-I, Q60.

Q63. Write short note on sunrise, sunset and day length.

Answer :

Sunrise and Sunset

The sunrise and sunset times, and the duration of the day length mainly depend upon the latitude of the location and season and the month or day in the year.

At sunrise and sunset, the sunlight is parallel to the ground surface. Thus, the zenith angle is 90°.

The hour angle corresponding to the sunrise and sunset is given as,

$$\cos\omega_s = -\tan\phi\tan\delta$$

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

The sunrise hour angle is positive and sunset hour angle is negative.

Day Length

Day length is defined as the time interval between the sunrise and sunset.

The total angles between the sunrise and sunset is given as,

i.e., Total day length. $T_d = \omega_s + \omega_s$

$$= 2\omega_s = \cos^{-1}(-\tan\phi\tan\delta)$$

Since 15° of the hour angle is equivalent to one hour, the total day length in hours is given as,

$$T_d = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta)$$

Since the day length depends upon latitude of the location and season and day in the year, the following observations are made.

(i) The day length is shorter during winter as the sun rises late and sets early.

(ii) The day length is longer during summer, as the sun rises early and sets late

(iii) The difference in day length between summer and winter becomes more and more with the increase of the latitude angle.

Q64. List out the steps involved in the calculation of local solar time and day length and give needed formulae.

Answer : May-17, (R13), Q3(b)

Local Solar Time

Local Solar Time is also known as the Local Apparent Time (LAT). Local Solar Time (LST) is the time used for calculating hour angle (ω) does not match with the local clock time. This time can be obtained from the standard time observed on a clock by applying following two corrections.

First correction

This correction arises because of the difference in longitude between a location and the meridian on which the standard time is observed. For every degree of difference in longitude, the magnitude of this correction is 4 minutes.

Second Correction

This correction arises because of the small perturbations that occur in the earths orbit and rate of rotation. This correction is also called as the 'equation of time correction', and it based on the experimental observations as plotted in below figure.

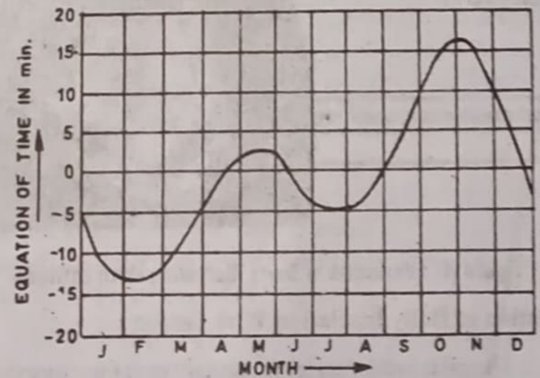


Figure : Graph Equation of Time (E) Correction

Therefore the local solar time or local apparent time is given by,

LST or LAT = Standard time ± 4 (standard time longitude – Longitude of Location) + (Equation of time correction)

(i) + ve sign is used for the western hemisphere.

(ii) –ve sign is used for the eastern hemisphere.

Q65. Define daily insolation. Explain its variation of with season and latitude.

Answer :

May-17, (EEE), (R13), Q3(b)

Solar Insolation

Total radiation is the sum of the beam radiation and diffuse radiation. When it is measured at any particular point or location on the earth's surface, it is called solar insolation.

Variation of Insolation with Latitude

The sun's rays strike the earth's surface at different angles angles at different locations depending on the latitude of the location. When the latitude is high, the angle made by the sun's rays with the surface of the earth is less. Thus, the sun's rays have to traverse longer distances and spread over a larger area. Due to this reason, the amount of reflection and absorption of heat by the atmosphere is more. As a result, the intensity of insolation is less. When the sun's rays strike the earth's surface vertically, the area covered is less compared to that of slant rays. Therefore, the solar radiations is concentrated over a small surface area and results in increased intensity insolation.

For example, when the sun's rays strike Earth's surface near the equator, the incoming solar radiation is more direct, i.e., nearly perpendicular or closer to a 90° angle. Thus, the intensity of insolation is higher at the equator.

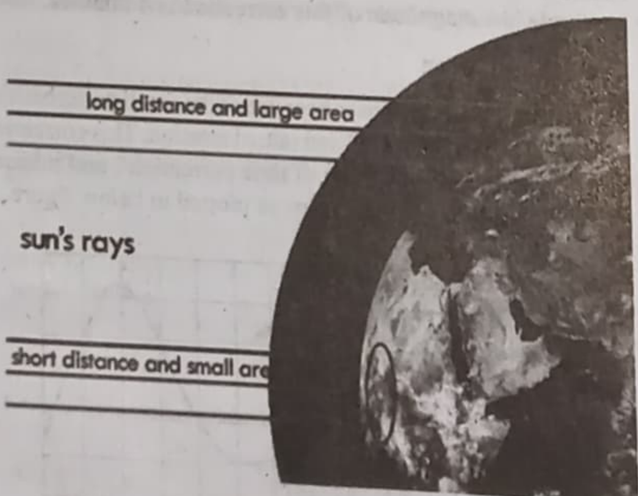


Figure (1) : Variation of Daily Insolation With Latitude

Variation of Daily Insolation With Season :

The solar insolation is not constant over the entire surface of the earth. It is more near the equator, because of the curvature of the earth.

Generally, the earth is tilted on its axis of rotation by 23.5°. As the earth revolves around the sun, the direction and angle or tilt of the earth's axis of rotation do not change. Therefore, when the earth rotates around the sun, the insolation is concentrated in the northern hemisphere (i.e., summer in the northern hemisphere) and then the southern hemisphere (winter in the northern hemisphere). This is the main reasons for having different seasons in a year

The hemisphere, either Northern or Southern hemisphere, whichever is tilted towards the sun receives more direct rays (i.e., the that are closer to perpendicular or at an angle of 90°) of the sunlight. The day length also more for the hemisphere tilted toward the sun than the hemisphere that is tilted away from the sun. The combined effect of more direct rays of sunlight and increased day length results in higher amount of daily insolation in the hemisphere tilted towards the sun.

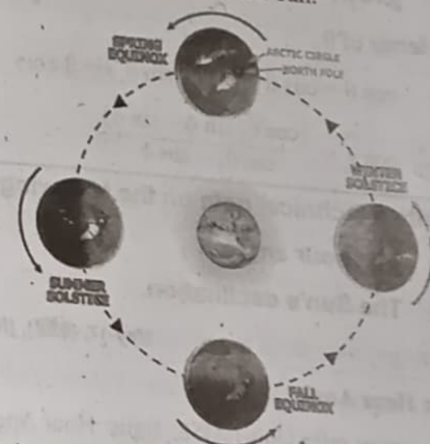


Figure (2) : Variation of Daily Insolation With Season

1.1.3 Solar Radiation on Tilted Surface, Instruments for Measuring Solar Radiation and Sunshine, Solar Radiation Data

Q66. Explain the need for determining the solar radiation on tilted surfaces.

Answer :

May-19, (R15), Q3(a)

Need For Determining Solar Radiation on Tilted Surfaces

The angle at which a surface is inclined with respect to sun, affects the rate of absorption of solar radiation by the surface. If a surface is made to tilt at a fixed angle with the horizontal, it will absorb less radiation when compared to the surface which is allowed to track the sun's motion continuously. It is beneficial to absorb as much as possible amount of solar radiation on the area of the given surface, since the solar radiation is a dilute form of energy.

Most of the solar radiation measuring instruments measure the solar radiation falling on horizontal surface. Therefore, it is necessary to convert the values measured on horizontal surface to the corresponding values on the tilted surface.

Thus, it is important to measure the solar radiation on tilted surfaces to adjust the surface to a optimum orientation so that maximum amount of solar radiation can be captured.

Q67. How to calculate solar radiation on tilted surfaces?

Answer : [April-18, (EEE), (R13), Q2(a) | May-17, (ME), (R13), Q3(a)]

The total solar radiation incident on any surface comprises of following three components.

1. Beam solar radiation
2. Diffuse solar radiation
3. Reflected solar radiation from ground and surroundings.

Generally, the flat plate collectors tilt automatically such that they always face the sun by using a sun tracking device to obtain maximum amount of solar energy. But most of the solar radiation measuring instruments measure solar radiation falling on a horizontal surface. Therefore, it is necessary to convert the values measured on horizontal surfaces to the respective values on the tilted surfaces.

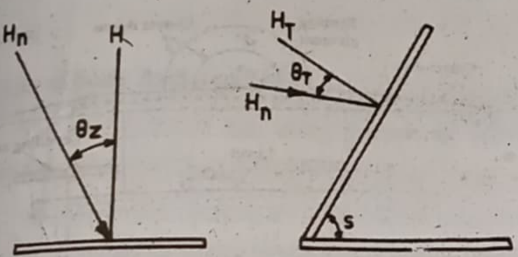


Figure : Radiation on Horizontal and Tilted Surface

1. **Beam Radiation**

Generally, the tilted surface faces south so that maximum solar radiation is obtained even during winter,

Since the surface is facing south, $\delta = 0$

And, $\cos\theta = \sin\delta\sin(\phi-\beta) + \cos\delta\cos\omega\, \mathrm{co}\delta(\phi-\beta)$

For a horizontal surface, $\theta = \theta_z$

Therefore, $\cos\theta_z = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega$

The ratio of the beam radiation falling on the tilted surface (H_T) to the beam radiation falling on the horizontal surface (H) is known as tilt factor for beam radiation. It is given by,

$$R_b = \frac{H_T}{H} \quad \text{... (1)}$$

From figure,

$$R_b = \frac{H_n\cos\theta_T}{H_n\cos\theta_z} = \frac{\cos\theta_T}{\cos\theta_2} \quad \text{... (2)}$$

$$\therefore R_b = \frac{\sin(\phi-\beta)\sin\delta + \cos(\phi-\beta)\cos\delta\cos\omega}{\sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega} \quad \text{... (3)}$$

2. **Diffuse Radiation**

The ratio of diffuse radiation falling on the tilted surface (H_d) to that falling on horizontal surface is known as 'tilt factor for diffuse radiation'. It is dented by symbol ; R_d.

Consider that the sky is an isotropic source of diffuse radiation. Then R_d for an inclined surface with a slope 's' is given by,

$$R_d = \frac{1+\cos\beta}{2} \quad \text{... (4)}$$

Where, $\frac{(1+\cos\beta)}{2}$ is the radiation shape factor for the tilted surface with respect to the sky.

3. **Reflected Solar Radiation**

The reflected component of solar radiation mainly comes from the ground and other surrounding objects. If the reflected radiation is considered as diffuse and isotropic, then the tilt factor for reflected radiation is given by,

$$R_r = \rho\left(\frac{1-\cos\beta}{2}\right) \quad \text{... (5)}$$

Where,

ρ – Reflectivity of the ground ($\rho = 0.2$, if the surface not covered with snow, and $\rho = 0.7$, if the surface is covered with snow)

$\frac{1-\cos\beta}{2}$ – Radiation shape factor for the surface with respect to the surroundings.

Total Radiation

The total radiation flux falling on the tilted surface is given by,

$$H = H_bR_b + H_dR_d + (H_b + H_d)R_r \quad \text{... (6)}$$

$$= H_bR_b + H_d\left(\frac{1+\cos\beta}{2}\right) + (H_b + H_d)\left(\frac{1-\cos\beta}{2}\right)\rho \quad \text{... (7)}$$

Q68. Briefly discuss about the Pyrheliometer.

Answer :

Pyrheliometer is an instrument used for measuring the beam or direct radiations. It collimates the radiation to measures the beam intensity as a function of incident angle.

Pyrheliometers are of three types. They are,

1. Angstrom pyrheliometer
2. Abbot silver disc Pyrheliometer
3. Eppley pyrheliometer.

To measure the beam radiation correctly, the receiving surface of the instrument should be normal to the solar radiation, i.e., the receiver and the sun should be in same line. To achieve this, the pyrheliometer is mounted on a sun-tracking device known as equatorial mount.

Unlike pyranometer in this instrument the sensor disc is located at the base of a tube, and tube axis is aligned with the direction of the sun's rays so that the diffuse radiation is blocked from reaching the surface of the sensor.

The pyrheliometers used common measurements are mostly operated on the thermopile effect. A collimator tube is installed over the sensor with a circular cone angle of about 5° to prevent the diffuse component reaching the sensor surface.

Q69. Explain the working of Pyrheliometer with the help of neat sketch.

June-18, (R13), Q2(b)

OR

Explain the working of pyrheliometer with the aid of a neat diagram.

Answer :

April-14, (R09), Q1(b)

Angstrom Pyrheliometer

It is the most commonly used pyrheliometer for the measurement of direct or beam radiation. This instrument consists of a thin blackened shaded manganin strip of size 20 × 2 × 0.1 mm. This strip is heated by electric current till its, temperature becomes equal to that of a similar strip exposed to solar radiation. A schematic diagram of this pyrheliometer is shown in below figure. When both the strips are at equal temperature, the electrical energy used for heating is equal to the energy absorbed due to solar radiation. Two thermocouples are mounted on the back of each strip, and these are connected in opposition through a sensitive galvanometer or any other null detector. The setup of these thermocouples and galvanometer is used for testing the equality of temperature.

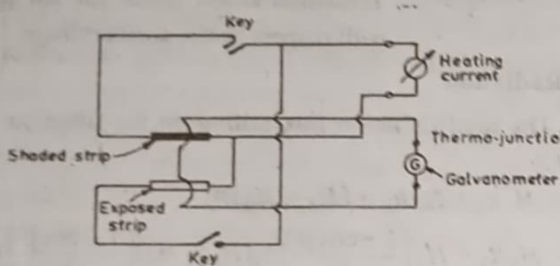


Figure : Electric Circuit for Angstrom Pyrheliometer

The following relation is used for determining the energy of the direct radiation,

$$H_{DN} = Ki^2.$$

Where,

H_{DN} – Direct radiation incident on an area normal to sun's rays

i – Heating current (A)

$\left(K = \dfrac{R}{W\alpha}\right)$ – Dimension and instrument constant

Q70. With the help of a neat diagram, explain about Pyranometer.

July-19, (R15), Q2(b)

OR

Explain the working of pyranometer with the help of neat sketch.

[Sept.-20. (R16), Q3(b) | April-18, (ME), (R13), Q2(b)]

OR

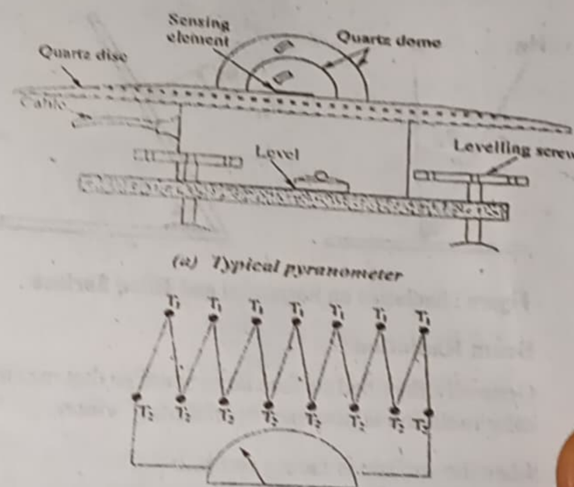
With the help of a neat diagram, explain about Eppley pyranometer.

Answer :

Eppley Pyranometer

This pyranometer works based on the principle that states, "there is a difference in temperatures of the black surfaces (absorbs most of the solar radiation) and the white surfaces (reflects most of the solar radiation)".

In this pyranometer, the receiver surface consists of two concentric silver rings. These rings are of 0.25 mm in thickness, and the inner ring is coated with black color and the outer ring is coated with white magnesium oxide. In between these coated rings, either 10 or 50 thermocouple junctions are installed to detect the temperature difference. This whole assembly of wedges or disks is enclosed in a hemispherical glass cover. The schematic diagram of the Eppley pyranometer and thermopile arrangement consisting of a battery of thermocouples connected in series is shown in below figure.



Figure

These pyranometer are calibrated in a horizontal position. If the instrument is inclined to measure the radiation on the surface other than a horizontal surface, the calibration of these instruments will vary to some degree.

Q71. Explain the working of sunshine recorder with the help of a neat sketch.

Answer :

[July-19, (R15), Q3(a) | May-19, (R15), Q2(b) | June-18, (R13), Q1(b) | April-18, (ME), (R13), Q3(b)]

Sunshine recorder is an instrument used for measuring the hours of bright sunshine in a day.

It consists of a glass sphere which is mounted concentrically inside of section of a spherical metal bowl. This spherical bowl is provided with grooves for holding a recorder card strip and the glass sphere. The glass sphere acts as a convex lens, thus it focusses the sun's rays to a point on the card strip.

A schematic diagram of sunshine recorder is shown in below figure.

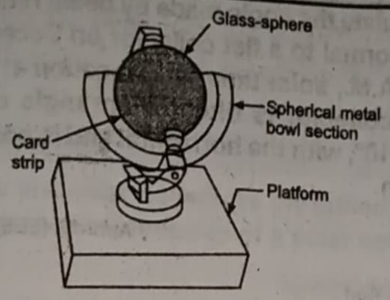


Figure : Sunshine Recorder

When the sunshine is bright, the intensity of the image formed due to focussed sun's rays is sufficient enough to burn a spot on the card strip. Since the sun moves across the sky throughout the day the image moves along the card strip. The length of the burnt space (or image formed) is directly proportional to the duration of bright sunshine.

Q72. What are the features of solar radiation data?

Answer :

Features of Solar Radiation Data

The solar radiation data should include the following information.

1. Weather the data obtained are instantaneous measurement or the values integrated over a period of time (generally an hour or a day)
2. The time or time period of the measurements.
3. The orientation of the receiving surface, i.e., weather it is horizontal or inclined at a fixed slope or normal.
4. The type of radiation measured (i.e., beam, diffuse or total radiation) and the instruments used for the measurement.
5. If the data is averaged, the period over which the measurements are averaged.

Q73. Classify the instruments used for measurement of solar radiation and discuss in brief.

Answer : July-21 (ME), (R16), Q3(b)

Instruments used for Measuring Solar Radiation

For answer refer Unit-I, Q15.

Working Principle of Pyranometer

For answer refer Unit-I, Q16.

Working Principle of Pyrheliometer

For answer refer Unit-I, Q68.

Q74. Explain the methods of measuring solar radiation.

Answer : May-19, (R15), Q3(b))

Solar radiation can be measured by using following three instruments.

1. **Pyranometer**

For answer refer Unit-I, Q70.

2. **Pyrheliometer**

For answer refer Unit-I, Q68.

3. **Sunshine Recorders**

For answer refer Unit-I, Q71.

Q75. Explain what is meant by sunshine recorder and solar radiation data?

Answer : April-18, (EEE), (R13), Q3(a)

Sunshine Recorder

For answer refer Unit-I, Q71.

Solar Radiation Data

For answer refer Unit-I, Q72.

Q76. Calculate the angle made by the beam radiation with normal to a flat plate collector, pointing due south located New Delhi (28°38'N, 77°17'E) at 9:00 hr, solar time on December 1. The collector is tilted at an angle of 36° with the horizontal.

[May-17, (ME), (R13), Q2(b) | April-18, (EEE), (R13), Q2(b)]

Answer :

Given that,

Time = 9 hours (LST)

Latitude, $\phi_l = 28°38' = 28.63°$ $(\because 1° = 60')$

Day of the year = December 1

Angle of tilt, $\beta = 36°$

$$\text{Total number of days, } n = [31+28+31+30+31+30+31+31+30+31+30+1] = 335$$

Since the collector is pointing due south, the surface azimuth angle is zero, i.e., $\gamma = 0$

$$\text{Declination angle, } \gamma = 23.45 \sin\left[\frac{360}{365}(284+n)\right]$$

$$= 23.45 \sin\left[\frac{360}{365}(284+335)\right]$$

$$= 23.45 \sin 610.52°$$

$$\gamma = -22.11°$$

Solar hour angle (ω) is given by,

$$\omega = 15(12 - LST)$$

$$\omega = 15\,(12-9)$$

$$\therefore \quad \omega = 45°$$

Since the flat collector is pointing due south, $\gamma = 0$

For this case, the incident angle is calculated from the following equation.

$$\cos\theta_T = \cos(\phi_l - \beta)\cos\delta\cos\omega + \sin(\phi_l - \beta)\sin\delta$$
$$= \cos(28.63° - 36°)\cos(-22.11°)\cos(45°) + \sin(28.6° - 36°)\sin(-22.11°)$$
$$= \cos(-7.37°)\cos(-22.11°)\cos(45°) + \sin(-7.4°)\sin(-22.11°)$$
$$= 0.6496 \simeq 0.65$$
$$\cos\theta_T = 0.65$$
$$\theta_T = \cos^{-1}(0.65)$$
$$\theta_T = 49.46°$$

$\therefore$ The angle made by the beam radiation with the normal to a flat plate collector, is 49.46°.

Q77. Calculate the angle made by the beam of radiation with normal to the flat collector on June 1 at 11.00 AM solar time for the location latitude 16°98'N. The collector is tilted at angle of latitude plus 15° with horizontal and it is pointing due south.

Answer :

Given that,

Time, LST = 11 hours

Latitude, $\phi = 16°98'$ $\quad (\because 1° = 60')$

For June 1,

$$n = [31 + 28 + 31 + 30 + 31 + 1]$$
$$= 152 \text{ days}$$

Angle of tilt, $\beta = 16° + 15° = 31°$.

As the collector is pointing due to south, the surface azimuth angle (γ) is zero.

$$\text{Solar declination, } \delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$
$$= 23.45 \sin\left[\frac{360}{365}(284 + 152)\right]$$
$$= 23.45 \sin 430.027°$$
$$\delta = 22.039°$$

Solar hour angle (ω) is given by,

$$\omega = 15(12 - LST)$$

Where,

LST – Mean local solar time

$$\omega = 15(12 - 11) = 15°$$

The angle made by beam radiation for the tilted surface pointing due to south is given by,

$$\cos\theta_T = \cos(\phi - \beta)\cos\delta\cos\omega + \sin(\phi - \beta)\sin\delta$$
$$= \cos(16° - 31°)\cos(22.039°)\cos(15°) + \sin(16° - 31°).\sin(22.039)$$
$$= \cos(-15°)\cos(22.039°)\cos(15°) + \sin(-15°)\sin(22.039°)$$
$$= 0.864 + (-0.097)$$
$$\cos\theta_T = 0.767$$
$$\theta_T = \cos^{-1}(0.767)$$
$$\theta_T = 39.914°.$$

$\therefore$ The angle made by the beam radiation with the normal to a flat plate collector, $\theta_T = 39.914°$.

Q78. Calculate the angle made by beam radiation with the normal to a flat collector on December 1, at 9.00 A.M., solar time for a location at 28° 35' N. The collector is tilted at an angle of latitude plus 10°, with the horizontal and is pointing due south.

Answer : April-18, (EEE), R13), Q3(b)

Given that,

Time, LST = 9 hours

Latitude, $\phi = 28°35'$ $\quad (\because 1° = 60')$

For December 1,

$$n = [31 + 28 + 31 + 30 + 31 + 30 + 31 + 31 + 30 + 31 + 30 + 1]$$
$$= 335 \text{ days}$$

Angle of tilt, $\beta = 28° + 10° = 38°$.

As the collector is pointing due to south, the surface azimuth angle (γ) is zero.

$$\text{Solar declination, } \delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$
$$= 23.45 \sin\left[\frac{360}{365}(284 + 335)\right]$$
$$= 23.45 \sin 610.52°$$
$$\delta = -22.11°$$

Solar hour angle (ω) is given by,

$$\omega = 15(12 - LST)$$

Where,

LST – Mean local solar time

$$\omega = 15(12 - 9) = 45°$$

The angle made by beam radiation for the tilted surface pointing due to south is given by,

$$\cos\theta_T = \cos(\phi - \beta)\cos\delta\cos\omega + \sin(\phi - \beta)\sin\delta$$
$$= \cos(28° - 38°)\cos(-22.11°)\cos(45°) + \sin(28° - 38°)\sin(-22.11°)$$
$$= \cos(-10)\cos(-22.11°)\cos(45°) + \sin(-10)\sin(-22.11°)$$
$$= 0.6451 + 0.0653$$
$$\cos\theta_T = 0.7104$$
$$\theta_T = \cos^{-1}(0.7104)$$
$$\theta_T = 44.7325°$$

$\therefore$ The angle made by the beam radiation with the normal to a flat plate collector, $\theta_T = 44.7325°$.

1.2 SOLAR ENERGY COLLECTION - FLAT PLATE AND CONCENTRATING COLLECTORS - CLASSIFICATION OF CONCENTRATING COLLECTORS - ORIENTATION AND THERMAL ANALYSIS - ADVANCED COLLECTORS

Q79. How are solar collectors classified? What are the important features of a solar collector?

April-18, (ME), (R13), Q5(a)

Answer :

Classification of Solar Collectors

Solar collectors are mainly classified into two categories. They are,

1. Non-concentrating (or) Flat plate collectors.

   These are sub-classified into two types.

   They are

   (i) Liquid heating collectors

   (ii) Air heating collectors

2. Concentrating collectors.

   These are classified into two types. They are

   1. Focusing type collectors.

      (i) Line focusing collectors

         (a) Parabolic trough collectors.

         (b) Mirror-strip reflector

         (c) Fresnel lens collector

      (ii) Point focusing collector (paraboloidal collectors).

   2. Non focusing type collector

      (i) Flat plate collector with adjustable mirrors

      (ii) Compound parabolic concentrator (CPC)

Important Features of a Solar Collector

The three important features of solar collector are,

1. **Collector Efficiency (η_c)**

   For answer refer Unit-II, Q29, Topic: Collector Efficiency.

2. **Concentrating Ratio (CR)**

   Concentration ratio is defined as the ratio of effective area of the aperture to the solar energy absorber.

   $$\text{i.e., CR} = \frac{\text{Effective aperture area}}{\text{Absorber tube area}}$$

3. **Temperature Range of the Working Fluid**

   In case of flat plate collectors, the fluid temperatures upto 100°C can be obtained. Whereas, in case of concentrating type collectors, the fluid temperature can be increased upto 500°C.

Q80. Explain with constructional features of solar flat plate collector for efficient conversion.

May-19, (R15), Q4(a)

OR

Enumerate, with suitable schematic, on the construction details of a flat plate collector.

May-17, (EEE), (R13), Q5(a)

OR

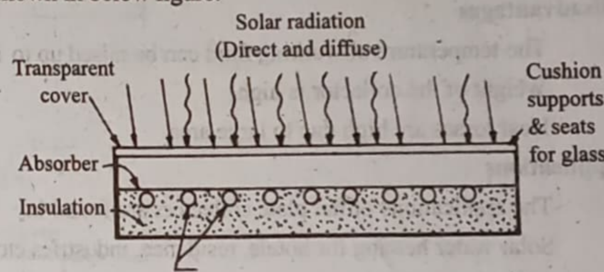
Briefly explain flat plate collector with neat diagram.

Answer :

The flat plate collectors mainly consists of five major components. They are,

1. Transparent cover
2. Tubes or channels
3. Absorber plate
4. Insulation
5. Casing or container.

The schematic cross section of a flat plate collector is shown in below figure.



Figure

1. **Transparent Cover**

   The transparent cove is placed above the absorber plate. It can be one or more number of sheets of glass or radiation transmitting plastic film or sheet of thickness 4 mm or 5 mm. It allows the solar radiation to reach the absorber plate and reduces the heat losses due to convection, conduction and re-radiation.

2. **Turbines or Channels**

   The tubes, fins and channels or passages are integral parts of the absorber plate or connected to it. The working fluid flows through these tubes and absorbs the heat from the absorber plate.

   The tubes are made from a metal (usually copper) and the diameter is ranging from 1 cm to 15 cm. These tubes are attached to the bottom of the absorber plate by soldering, brazing, welding or pressure bonding process with a pitch ranging from 5 cm to 15 cm. Sometimes, these tubes are bonded to the top or in line and integrated with the absorber plate. The header pipes are also made of copper with a diameter of 2 to 2.5 cm and in these pipes, water passes in and out of the collector and distribute to the tubes.

3. **Absorber Plate**

The absorber plate is usually a metallic plate with black surface. It is made of materials having high thermal conductivity such as copper, aluminium or steel. Some time plastic plates also used for low temperature applications. In order to improve the absorption of solar radiation, the absorber plates are coated with various materials. These coatings can be tailer made to serve the specific functions like minimizing the amount of infrared radiation emitted.

The absorber plate is generally made from a metal sheet of thickness ranging from 0.2 m to 1 mm. The material used for absorber plate are copper steel, aluminium or corrugated galvanized steel.

4. **Insulation**

Insulation is provided at the bottom and sides of the absorber plate to minimize the heat losses. Generally,the standard insulating materials such as fibre glass or styrofoam are used.

5. **Casing or container**

The casing or container is a box like structure made of metallic sheet or fibre glass, which encloses all the parts of the collector and protects them from weather.

Q81. Write the advantages, disadvantages and applications of flat plate solar collector.

Answer :

Advantages

1. Both beam (direct) and diffuse radiations can be absorbed.
2. Require little maintenance
3. The orientation towards the sun is not required, i.e., no tracking device is required.
4. Mechanically simpler compared to concentrating reflectors, absorbing surfaces and orientation devices of focussing collectors.

Disadvantages

1. The temperature of working fluid can be raised up to 100°C only, which is very low.
2. Weight of the collector is high.
3. Heat losses are high due to large area

Applications

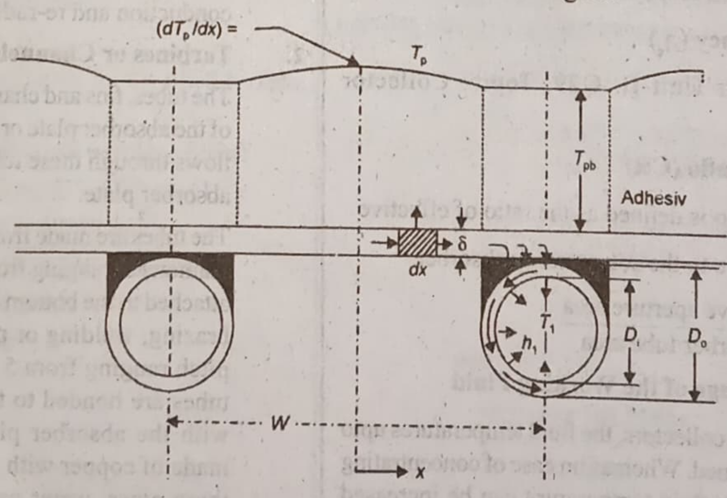
The applications of flat plate collectors are found in,

1. Solar water heating for hotels, residence, industries etc.
2. Solar heating and cooling.
3. Low temperature power generation.
4. Solar cookers for domestic cooling
5. Solar drying applications.

Q82. Give a brief account of thermal analysis of a flat plate collector.

Answer : June-18, (R13), Q5(b)

Consider a section of the absorber with two adjacent tubes as shown in below figure.



Figure

Since the sheet material is a good conductor, the temperature gradient in the flow direction is negligible.

Let,

W – Length of the absorber plate between tubes

D_i – Inside diameter of the tubes

D – Outside diameter of the tubes

δ – Thickness of sheets

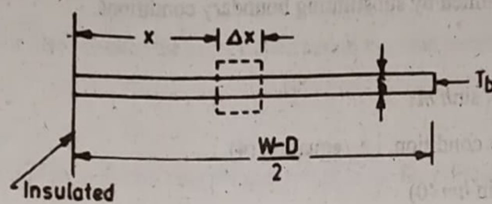
Assumptions

(i) The temperature in the plate (T_p) will vary in x - direction

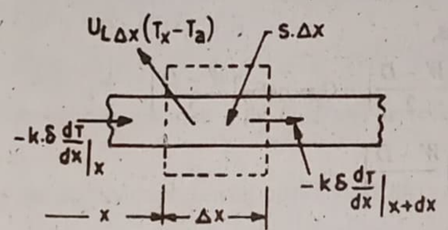
(ii) The temperature distribution is same between any two tubes.

(iii) The sheet above the bond to be at same local base temperature T_b i.e., the temperature above the fluid tubes is constant, and in between the tubes,the temperature will pass through a maximum.

The region between the centre line separating the tubes and the tube base can be considered as a classical fin system. The energy balance for the fin element is shown in below figure.



(a)



(b)

Figure

The fin length is given by, $\dfrac{W-D}{2}$

The energy balance for a small elemental region 'Δx' and unit length in the flow direction is given as,

$$S\Delta x - U_L\,\Delta x(T_P - T_a) + \left(-k\delta\frac{dT_P}{dx}\right)_x - \left(-k\delta - \frac{dT_P}{dx}\right)_{x+dx} = 0 \qquad ...(1)$$

$$S\Delta x + U_L(T_a - T_P)\Delta x - k\delta\frac{dT_P}{dx} - \left[k\delta\frac{d}{dx}(T_P + dT_p)\delta x\right] = 0$$

$$S\Delta x + U_L(T_a - T_P)\Delta x - k\delta\frac{dT_P}{dx} + k\delta\frac{dT_P}{dx} + k\delta\frac{d^2T_p}{dx^2}\Delta x = 0$$

$$S\Delta x + U_L(T_a - T_P)\Delta x = k\delta\frac{d^2T_P}{dx^2}\Delta x$$

$$S + U_L(T_a - T_P) = -k\delta\frac{d^2T_P}{dx^2}$$

$$\frac{d^2T_P}{dx^2} = \frac{U_L}{k\delta}\left(T_P - T_a - \frac{S}{U_L}\right) \qquad ...(2)$$

The equation (2) is a second order differential equation. It is solved by following two boundary conditions,

1. $\frac{dT_P}{dx}\big|_{x=0} = 0$

2. $T_P\big|_{x=\frac{W-D}{2}} = T_b$

Let, $m^2 = \frac{U_L}{k\delta}$ and $\psi = T_p - T_a - \frac{S}{U_L}$

Then, the equation (2) becomes,

$$\frac{d^2\psi}{dx^2} - m^2\psi = 0 \quad \text{...(3)}$$

The boundary conditions equation (3) are given by,

1. $\frac{d\psi}{dx}\big|_{x=0} = 0$ ...(4)

2. $\psi\big|_{x} = \frac{W-D}{2} = T_b - T_a - \frac{S}{U_L}$ ...(5)

The general solution of the above equation is

$$\psi = C_1 \sinh mx + C_2 \cosh mx \quad \text{...(6)}$$

The constant C_1 and C_2 are determined by substituting boundary conditions.

Then,

$$\frac{d\psi}{dx} = C_1 m \cosh mx + C_2 m \sinh mx$$

By substituting the first boundary condition, i.e., equation (4),

$$0 = C_1 m\cos hm(0) + C_2 m \sin hm\ (0)$$

$$\therefore \quad C_1 = 0$$

From second boundary conditions,

$$T_b - T_a - \frac{S}{U_L} = (C_1)\cos hm\left(\frac{W-D}{2}\right) + C_2 m\cosh m\left(\frac{W-D}{2}\right)$$

$$T_b - T_a - \frac{S}{U_L} = C_2 m\cosh m\left(\frac{W-D}{2}\right)$$

$$\therefore \quad C_2 = \frac{T_b - T_a - \frac{S}{U_L}}{\cosh m\left(\frac{W-D}{2}\right)}$$

Then, the equation (b) becomes,

$$T_p - T_a - \frac{S}{U_L} = \frac{T_b - T_a - \frac{S}{U_L}}{\cosh m\left(\frac{W-D}{2}\right)}\cosh mx \quad \text{...(7)}$$

$$\frac{T_P - T_a - \frac{S}{U_L}}{T_b - T_a - \frac{S}{U_L}} = \frac{\cos hmx}{\cos hm\left(\frac{W-D}{2}\right)} \quad \text{...(8)}$$

The rate of energy conducted through the plate to one of the fluid tube from both sides per unit length in the flow direction is given by,

$$q_{\text{fin base}} = -2k\delta\frac{dT_p}{dx}\big|_{x=\frac{W-D}{2}}$$

From equation (8),

$$\frac{dT_P}{dx} = \left(T_b - T_a - \frac{S}{U_L}\right)\frac{m\sinh mx}{\cosh m\left(\frac{W-D}{2}\right)}$$

$$\therefore \quad q_{finbase} = -2k\delta\left[\left(T_b - T_a - \frac{S}{U_L}\right)\frac{m\sinh m\left(\frac{W-D}{2}\right)}{\cosh m\left(\frac{W-D}{2}\right)}\right]$$

$$= \frac{2k\delta m}{U_L}\left[S - U_L(T_b - T_a)\right]\tanh m\left(\frac{W-D}{2}\right)$$

$$= \frac{2}{m}\left[S - U_L(T_b - T_a)\right]\tanh m\left(\frac{W-D}{2}\right) \qquad \left(\because m^2 = \frac{U_L}{K\delta} \Rightarrow \frac{k\delta m}{U_L} = \frac{1}{m}\right)$$

$$= 2\left(\frac{W-D}{2}\right)\left[S - U_L(T_b - T_a)\right]\frac{\tanh m\left(\frac{W-D}{2}\right)}{m\left(\frac{W-D}{2}\right)}$$

$$= (W-D)\left[S - U_L(T_b - T_a)\right]F$$

Where, $F = \left\{\dfrac{\tanh m\left(\frac{W-D}{2}\right)}{m\left(\frac{W-D}{2}\right)}\right\}$, and is usually known as the fin efficiency.

The useful gain of the collector also includes the energy absorbed in the tube region, i.e., the energy collected above the tube region is given by,

$$q_{tube} = D[S - U_L(T_p - T_a)] \qquad ...(9)$$

Therefore, the total energy gain of the collector tube per unit length in the flow direction is given by,

$$\therefore \quad q_u = q_{finbase} + q_{tube}$$

$$= (W-D)\left[S - U_L(T_b - T_a)\right]F + D[S - U_L(T_b - T_a)]$$

$$\because \quad q_u = [(W-D)F + D]\,[S - U_L(T_b - T_a)] \qquad ...(10)$$

The heat from the absorber plate should be transferred to the fluid, and the resistance to this heat transfer comprises of following there components.

1. The resistance due to the bonding material used between the plate and the tube.
2. The resistance due to the temperature gradient in the fluid at the tube wall.
3. The resistance due to the tube wall thickness.

Therefore, $q_u = \dfrac{T_b - T_f}{\dfrac{1}{C_b} + \dfrac{1}{\pi D_i h_{fi}} + \dfrac{1}{C_w}}$ ...(11)

Where,

C_b – Conductance of the bond

C_w – Conductance of the tube wall

h_{fi} – Local heat transfer coefficient

T_f – Local fluid temperature

The conductance of the bond can be calculated as,

$$C_b = \frac{k_b b}{y}$$

Where,

k_b – Bond conductivity

b – bond length

y – Bond average thickness

The bond conductance is an important parameter to describe the collector performance very accurately. Simple wiring or clamping of the tubes to the sheet may result in significant loss in the collector performance. Thus, it is necessary to ensure a good metal to metal contact so that the bond resistance is less than 0.33 m °C/W.

From equations (10) and (11),

$$q_u = \frac{S - U_L(T_f - T_a)}{U_L\left[\frac{1}{U_L[(W-D)]F + D} + \frac{1}{C_a} + \frac{1}{\pi D_i h_{fi}} + \frac{1}{CW}\right]} \quad ...(12)$$

$$q_u = WF'[S - U_L(T_f - T_a)] \quad ...(13)$$

W here,

$$F' = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L[D + (W-D)F]} + \frac{1}{C_b} + \frac{1}{C_w} + \frac{1}{\pi D_i h_{fi}}\right]}$$

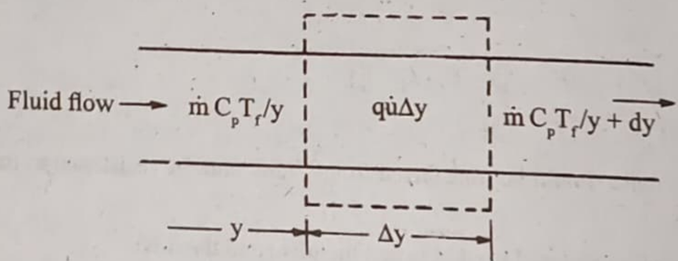
Where,

F' is called as the collector efficiency factor. It can also be represented as the ratio of thermal resistance between absorber plate and ambient air to the thermal resistance between fluid and ambient air.

i.e., $F' = \frac{U_o}{U_L}$

Generally, F' is a constant for any collector design and fluid flow rate.

To determine the temperature distribution in the flow direction, consider the energy balance on a fluid element flowing through a pipe of length Δy which is receiving a uniform heat flux q_u as shown in below figure.



Figure

$$\dot{m}C_P T_f|_y - \dot{m}C_P T_f|_{y+dy} + \Delta y . q_u = 0 \quad ...(14)$$

By dividing equation (14) by Δy and finding the limit as $\Delta y \to 0$, and substituting the value of q_u in equation (14).

$$\dot{m}C_P \frac{dT_f}{dy} - WF'[S - U_L(T_f - T_a)] = 0 \quad ...(15)$$

If F' and U_L are assumed to be constants (i.e., independent of y), the solution of the differential equation (15) for the temperature at any position is given by,

$$\frac{T_f - T_a - \frac{S}{U_L}}{T_{fi} - T_a - \frac{S}{U_L}} = e^{-\left(\frac{U_L WF'y}{\dot{m}C_P}\right)} \quad ...(16)$$

If the length of the collector is L in the flow direction, then the outlet temperature T_{fo} can be calculated by substituting L for y in the equation (16).

$$T_{fo} = T_a + \left(\frac{S}{U_L}\right) - \left[\frac{S}{U_L} - (T_{fi} - T_a)e^{-U_L F' A_C/\dot{m}C_p}\right] \quad ...(17)$$

Where,

$A_c = WL$ – The area of collector

The total useful energy collection rate is given by,

$$q_u = \dot{m}C_P(T_{fo} - T_{fi}) \quad ...(18)$$

By substituting 'T_{fo}' in equation (17),

$$q_u = A_C F_R [S - U_L(T_{fi}' - T_a)]$$

Where, $F_R = \frac{\dot{m}C_P}{A_C U_L}[1 - e^{-A_C U_L F'/\dot{m}C_P}] \quad ...(19)$

$$= \frac{GC_P}{U_L}[1 - e^{-U_L F'/GC_P}] \quad ...(20)$$

Where, $G = \dot{m}/A_C$

F_R is known as the heat removal factor of the collector.

Q83. Derive the equation for solar energy balance and collector efficiency. Write the advantages and disadvantages of flat plate collectors.

OR

Derive the equation for solar energy balance equation and collector efficiency their advantages and limitations.

Answer : May-17, (ME), (R13), Q4(a)

Solar Energy Balance Equation

The energy balance equation indicates the distribution of incident solar radiation into the useful energy gain and different energy losses. The thermal losses include conductive losses, convective losses and radiative losses.

Under steady state conditions, the energy supplied by a solar collector is equal to the difference between the energy absorbed by metal surface and energy lost from the surface to the surroundings (both directly and indirectly).

It can be represented in the form an equation as follows,

$$Q_u = A_C [HR\,(\tau.\alpha)_{eff} - U_L(T_p - T_a)]$$

Where,

Q_u – Useful energy delivered by the collector, (W or kcal/hr)

A_c – Area of the collector, (m^2)

HR – Solar energy received on the upper surface of the collector, (W/m^2 or kcal/hr.m^2)

τ – Transmissibility

α – Absorptivity

$(\tau.\alpha)_{eff}$ – Effective transmittance absorptance product of cover system for beam and diffuse radiation.

U_L – Overall heat loss coefficient (W/m^2°C)

T_P – The average temperature of the upper surface of the absorber plate, (°C)

T_a – Temperature of the atmosphere (°C)

The energy balance equation on the whole collector can be written as,

$$A_C[\{HR\,(\tau.\alpha)_b + HR\,(\tau.\alpha)_d\}] = Q_u + Q_l + Q_s$$

Q_u – Rate of useful heat transfer from the absorber pipes to the working fluid in the collector.

Q_l – Rate of energy losses from the collector to the surroundings by re-radiation, convection, conduction, etc.

Q_s – Rate of energy storage in the collector.

$(\tau.\alpha)_b$ – Transmittance absorptance product of cover system for beam radiation.

$(\tau.\alpha)_d$ – Transmittance absorptance product of cover system for diffused ration.

Collector Efficiency

Efficiency of a collector is defined as the ratio of the useful energy gain over any time period to the incident solar energy over the same time period.

$$\text{i.e., } \eta_c = \frac{\int Q_u dT}{\int HR dT}$$

Advantages and Limitations of Flat Plate Collectors

For answer refer Unit-I, Q81.

Q84. With the help of a neat diagram, explain the working of a concentrating collector.

July-19, (R15), Q4(a)

OR

Explain the various configurations for the concentrating collectors.

Answer : [May-13, (R09), Q2(a) | Model Paper, Q3(b)]

The main configuration of the concentrating collector are,

1. Parabolic trough collector
2. Mirror strip reflector
3. Fresnel lens collectors
4. Flat plate collectors with adjustable mirrors.
5. Compound parabolic concentrator (C.P.C)

1. Parabolic Trough Collector

The parabolic through collector is a line focussing type concentrating collector. The working principle of this type of collector is shown in below figure.

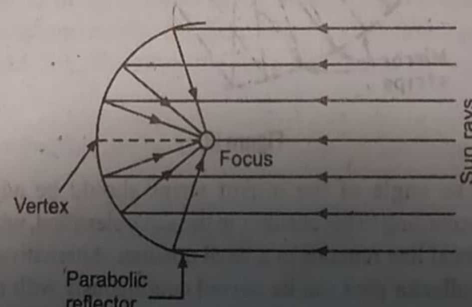


Figure (1)

In this collector, the solar radiation coming from the specific direction is collected over the area a of a parabolic reflecting surface. This surface reflects the solar radiation, which is concentrated at the focal point of the parabolic surface. The reflected solar radiation will be focussed along a line, if the reflecting surface is in the form of a trough with parabolic cross-section.

The cylindrical parabolic concentrators are widely used in which the absorber is placed along the focus axis as shown in below figure.

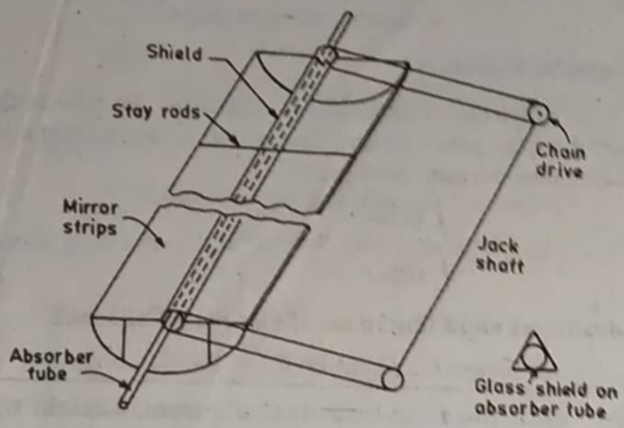


Figure (2)

2. **Mirror-Strip Reflector**

The mirror strip collector is type of line focussing collector. This collector consists of a number of plane mirrors or slightly curved or concave mirror strips that are mounted on a base. Each of these mirrors are mounted at a specific angle such that the reflected solar radiation from all the mirror strips fall on the same focal line as shown in below figure.

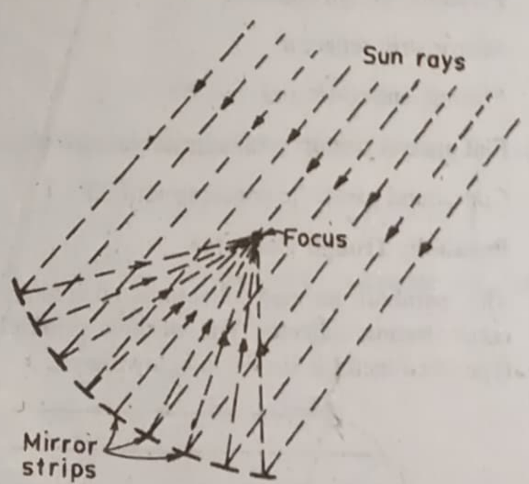


Figure (3)

The angle of the mirror strips should be adjusted according to the changes in the sun's elevation, while the focal line remains in a fixed position. Alternatively, the collector pipe can be moved continuously with respect to the changes in the sun's elevation, while the mirror strip are fixed.

3. **Fresnel Lens Collector**

In this collector a fresnel lens is used. The fresnel is made of an acrylic plastic sheet, and it has flat surface on one side and the fine linear grooves are made on the other side surface as shown in below figure.

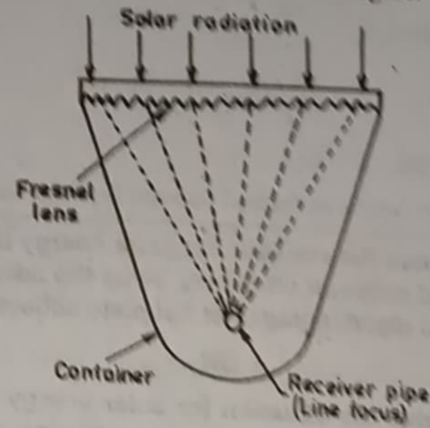


Figure (4)

The solar beam direct radiation that is falling on the lens perpendicularly is refracted by the lens. This refracted radiation is focussed on the focal line, when the absorber pipe is placed as shown in figure.

Generally, glass and plastic materials are used as refracting materials for fresnel lenses.

4. **Flat Plate Collector With Adjustable Mirrors**

The mirror boosted flat plate collector is the simplest type concentrating collector. This collector consists of a flat plate collectors facing south with mirrors attached to its north and south edges as shown in below figure.

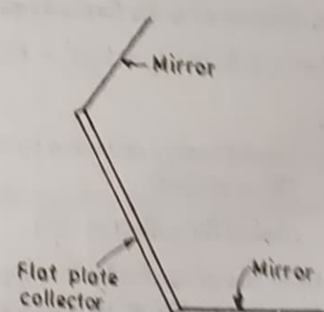


Figure (5)

The solar radiation fall normally on the absorber plate directly. The two mirrors when set at an appropriate angle, reflect the solar radiation on to the absorber plate.

This is an additional solar radiation falling on the surface. The angle of the mirrors should be adjusted according to the change in sun's altitude so the maximum amount of scattered radiation can be reflected on to the absorber plate.

Since the radiation reflected by the mirrors contributes to only a relatively small increase in the solar radiation falling on the absorber,this type of collector not widely used.

Compound Parabolic Concentrator (CPC)

The CPC or Winston collector is a trough like arrangement of two facing parabolic mirrors. These two mirrors are oriented such that focus of one mirrors is located at the bottom end of the other and viceversa as shown in below figure.

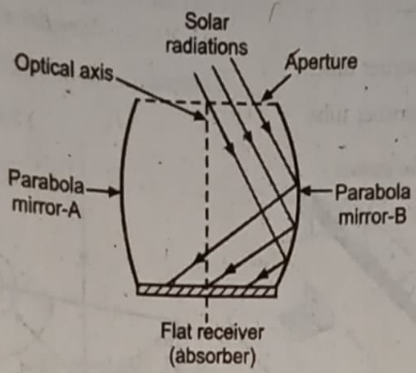


Figure (6)

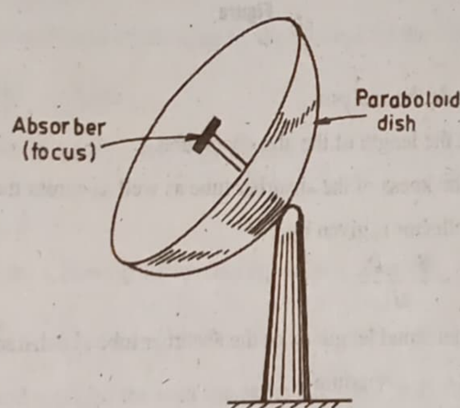
As shown in figure, the absorber plate or receiver is a flat surface parallel to the aperture joining of two foci of the reflecting mirrors. This collector has a large acceptance angle and it has to be adjusted intermittently. The solar radiation in the central region of the aperture reach the absorber directly. Where as the radiation near the edges undergo one or more reflections before reaching the absorber. With the use of this collector, the concentration ratios obtained in the range of 3 to 7.

Q85. Draw the line diagram and explain the working of paraboloidal point focussing collector.

Answer : April-18, (EEE), (R13), Q4(b)

The paraboloidal focussing collector, in which all the radiations from the sun are focused at a point.

The line diagram of a typical paraboloidal type point focussing collector is shown in below figure.



Figure

This collector consists of a dish of diameter 6.6 m, and is made from about 200 curved mirror segments forming a paraboloidal surface. The absorber is a cavity made of a zirconium copper alloy with a black chrome selective coating and it is located at the focus of the paraboloidal surface. The heat transport fluid flows into and out of the absorber cavity through pipes bonded to the interior. The paraboloidal dish has movement along two axes, i.e., it can automatically turn about two axes, up-down and left right so that the sun will be in line with the focus and the base (vertex) of the dish. Therefore, the sun can be tracked always by the collector.

The concentration ratios of this collector are very high, i.e., from 10 to few thousands. Therefore, it can be used where high temperature are required, i.e., up to 300°C.

Q86. Explain briefly about the performance analysis of a cylindrical parabolic collector.

Answer :

Consider a cylindrical parabolic collector as shown in below figure. Let the collector has either a concentric glass cover or a flat glass/plastic sheet covering the entire aperture area to protect the reflecting surface from environmental effects.

Let,

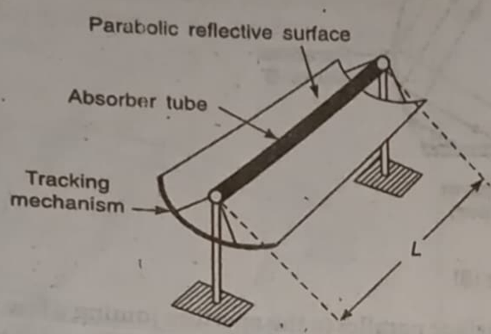
w – Width of concentrator or aperture.

L – Length of the concentrator.

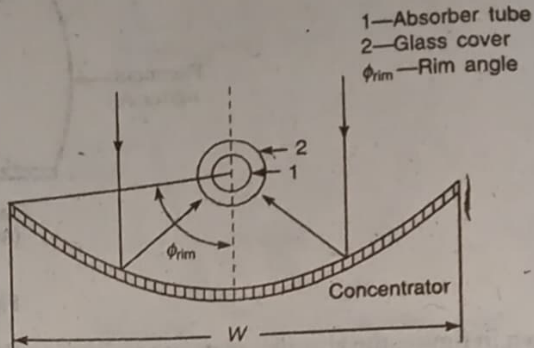
ϕ_{rim} – Rim angle.

D_i – Inner diameter of the absorber tube.

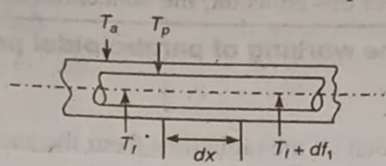
D_o – Outer diameter of the absorber tube.



(a) Cylindrical parabolic collector



(b) Cross section of the cylindrical parabolic collector,



(c) Cross section of the absorber tube

Figure

Assumptions :

The following assumptions are made for analysis,

1. Radiation flux is same throughout the length of the absorbers tube.
2. The temperature drop across the thickness of the absorber tube as well as across the glass cover is negligible.

The 'concentration ratio' of the collector is given by,

$$C = \frac{\text{Effective aperture area}}{\text{Absorber tube area}} = \frac{W - D_o}{\pi D_o} \quad \text{...(1}$$

For energy balance, consider an elemental length dx of the absorber tube at a distance x from the inlet.

Beam radiation normally incident o[n] aperture is $I_B R_b$.

Under steady state condition.

$$dQ_u = [I_b R_b (W - D_o)\, \rho r\, (\rho\alpha)_b + I_b R_B D_o\, (\tau\alpha)_b - U_l p D_o\, (T_p - T_a)]dx \quad \text{...(2}$$

Where,

dQ_u – Useful heat gain rate for a length dx

I_b – Beam radiation flux.

R_b – Beam radiation tilt factor

ρ – Specular reflectivity of the concentrator surface.

r – Intercept factor (fraction of the specularly reflected radiation intercepted by the absorber tube).

$(\tau\alpha)_b$ – Transmissivity – absorptivity product for beam radiation

U_l – Overall heat loss coefficient

T_p – Local temperature of absorber tube

T_a – Ambient temperature.

In equation (2),

(i) The first term represents the incident beam radiation on absorber tube after reflection.

(ii) The second term indicates the absorbed incident beam rad'at'on directly falling on the absorber tube. The is term can be ignored, when the top of the tube is insulated.

(iii) The third term is the loss by convection and re reradiation.

The absorbed radiation flux be given by,

$$S = I_b R_b \rho r(\tau\alpha)_b + I_b R_b(\tau\alpha)_b\left(\frac{D_o}{W - D_o}\right) \quad ...(3)$$

Then, equation (2) can be written as,

$$dQ_u = \left[S - \frac{U_1}{C}(T_p - T_a)\right](W - D_o)dx \quad ...(4)$$

The usefuel heat gain rate can alsobe expressed as follows,

$$dQ_u = h_f \pi D_i(T_p - T_f)dx \quad ...(5)$$

$$= \dot{m}c_p dT_f \quad ...(6)$$

Where,

D_i – Inner diameter of the absorber tube

h_f – Heat transfer coefficient on the inner surface of the tube.

T_f – Local fluid temperature

$\dot{m}$ – Mass flow rate of the fluid being heated in the collector

T_{fi} – Inlet temperature of the fluid

T_{fo} – Outlet temperature of the fluid

By combining the equation (5) and (6) and eliminating T_p, the relation for the useful heat gain becomes,

$$dQ_u = F'\left[S - \frac{U_1}{C}(T_f - T_a)\right](W - D_0)dx \quad ...(7)$$

Where, F' is the collector efficeincy factor, and it is given as,

$$F' = \frac{1}{U_e[(1/V_e) + (D_o/D_i h_f)]}$$

By solving equation (6) and (7) the following differential equation is obtained.

$$\frac{dT_f}{dx} = F'\pi\frac{D_o U_1}{\dot{m}c_p}\left[\frac{CS}{U_1} - (T_f - T_a)\right] \quad ...(9)$$

By integrating above equation and applying the inlet condition at $x = 0$, $T_f = T_{fi}$, the temperature distribution is obtained is obtained as,

$$\frac{[(CS/U_1) + T_a] - T_f}{[(CS/U_1) + T_a] - T_{fi}} = \exp\left(-\frac{F'\pi D_o U_1 x}{\dot{m}c_p}\right) \quad ...(10)$$

By substituting, $T_f = T_o$ and $x = L$ in equation (10), the outlet temperature of the fluid can be obtained.

By subtracting the terms on both sides from unity,

$$\frac{T_{fo} - T_{fi}}{[(CS/U_1) + T_a] - T_{fi}} = 1 - \exp\left(\frac{F'\pi D_o U_1 L}{\dot{m}c_p}\right) \quad ...(11)$$

The useful heat gain rate is given by,

$$Q_u = \dot{m}c_p(T_{fo} - T_{fi})$$

or $$Q_u = \dot{m}c_p\left(\frac{CS}{U_1} + T_a - T_{fi}\right)\left[1 - \exp\left(-\frac{F'\pi D_o U_1 L}{\dot{m}c_p}\right)\right]$$

$$= F_R(W - D_o)L\left[S - \frac{U_1}{C}(T_{fi} - T_a)\right] \quad ...(12)$$

Where, F_R is the heat removal factor and it is given as,

$$F_R = \frac{\dot{m}c_p}{\pi D_o L U_R}\left[1 - \exp\left(\frac{F\pi D_o U_1 L}{\dot{m}c_p}\right)\right] \quad \text{...(13)}$$

The instantaneous collection efficiency considering beam radiation only (i.e., neglecting ground reflected radiation) is given by,

$$\eta_{ib} = \frac{Q_u}{(I_b R_b)WL} \times 100 \quad \text{...(14)}$$

Generally the instantaneous collection efficiency, η_i, can be given as,

$$\eta_i = \frac{Q_u}{(I_b R_b + I_d R_d)WL} \times 100 \quad \text{...(15)}$$

The heat loss coefficient U_1 is given by,

$$U_1 = \left(\frac{1}{h_{wind}} + \frac{1}{h_r}\right) \quad \text{...(16)}$$

Where,

h_{wind} – Film coefficient due to wind

$= 5.7 + 3.8v$ W/m²°C (v is the wind velocity in m/s)

h_r – Radiation coefficient

The radiation coefficient h_r can be calculated as,

$$h_r(T_r - T_a) = \sigma\varepsilon_r(T_r^4 - T_a^4)$$

Where,

σ – Stefan – Boltzmann's constant (5.67×10^{-8} W/m² °C)

ε_r – Emissivity of the surface

T_r – Temperature of the radiant surface

Then,

$$h_r = \sigma\varepsilon_r(T_r + T_a)(T_r^2 - T_a^2)$$

Assume, $T_r = T_a$ and $\overline{T} = (T_r - T_a)/2$

$$\therefore h_r = 4\sigma\varepsilon_r \overline{T}^3 \quad \text{...(17)}$$

Q87 Explain the importance of orientation in concentrating type collectors and list the different types of sun trackers.

Answer : [July-21, (EEE), (R16), Q4(b) | Model Paper, Q2(b)]

Concentrating collectors are also known as focusing type solar collectors. These are a special type of flat plate collectors which make use of optical devices such as mirrors and lenses to converge or concentrate the sun's rays on the absorber. In these collectors, the radiation increases from lower value of 1.52 to high values of the order of 10000. These collectors, focus the radiation falling on a relatively large area on to a receiver or absorber of significantly smaller area. Because of this energy concentration, it is possible to heat the fluids to the temperature of 500°C or more.

The orientation of the sun from the earth changes continuously. Thus, it is necessary to keep the collector facing to sun rays direction, so that maximum solar rays can be harnessed. Hence, the orientation in concentrating collectors is necessary. This is achieved by using sun tracking devices.

The sun tracking devices are mainly categorised into two types.

1. **Single-Axis Solar Tracking Devices**

   These devices can adjust from east to west or north to south only according to the sun's position. These trackers can be furtherly classified into two types.

   (i) Centralised tracking devices

   (ii) Decentralised tracking devices

2. **Dual-Axis Solar Tracking Devices**

   The dual-axis solar tracking devices can track the position of the sun and can move in south and north or east and west directions.

Q88. Compare focusing collectors with flat plate collectors.

May-19, (R15), Q1(c)

OR

Differentiate between flat plat collectors and concentrating collectors?

May-17, (EEE), (R13), Q4(a)

Answer :

	Flat Plate Collectors		Concentrating Collectors
1.	These collectors are also called non-concentrating type solar collectors.	1.	These collectors are also called focussing type solar collectors.
2.	The collector area is equal to the absorber area.	2.	The collector area is very large, sometimes, hundreds of times larger than that of absorber area.
3.	The intensity of insolation is small.	3.	The intensity of insolation is very large.
4.	The reflecting surfaces require more material.	4.	The reflecting surface require less material.
5.	The working fluid temperature can be raised upto 100°C	5.	The working fluid temperature ban be raised up to 500°C.
6.	There is no use of mirrors and lenses to concentrate the sun's rays.	6.	Mirrors and lenses arrangement is used to concentrate the sun's rays.
7.	Absorbs both beam and diffused radiation.	7.	Absorbs mainly beam radiation and a little amount of diffused radiation falling directly on the absorber.
8.	Simple in construction and requires little maintenance	8.	Construction is complex and requires more maintenance.
9.	Heat losses are more due to larger area thus the efficiency is less.	9.	Heat losses are less as the radiation is concentrated thus the efficiency is more.

Q89. List out the advantages and disadvantages of concentrating collectors over a flat-plate collector.

July-21, (EEE), (R16), Q4(a)

Answer :

Advantages

The advantages of concentrating type collectors over flat plate collector are as follows,

1. For same solar energy, the absorber area of the concentrator collector is smaller than that of flat plate collector. Therefore, the intensity of solar insolation is more.
2. Less material in required for reflecting surfaces and these are structurally simpler than flat plate collector. Thus, the cost per unit are of solar collecting surface is significantly less than that of flat plate collectors.
3. Since the area from which the heat is lost to the surroundings is less than that of flat plate collectors and the insolation is more in concentrated collectors, the temperature of the working fluid can be raised to grater value than that of flat plate collector.
4. Since the absorber are of concentrating collectors is smaller, selective surface treatment and vacuum insulation to reduce heat losses and improve collector efficiency is economically viable.
5. When concentrating collectors are not used for heating or cooling operations, can be used for power generation. Therefore,the total useful operating time per year is larger than that of flat plate collectors.
6. The amount of heat storage per unit volume is higher, since the maximum temperature attained in case of concentrating plate is higher. Therefore, the heat storage costs are less.
7. The higher efficiencies can be obtained in solar heating and cooling applications than that of flat plate collectors.
8. The concentrating collectors require little or no anti-freeze to protect the absorber, whereas, in case of flat plate collector, the entire absorber surface requires anti freeze protection.

Limitations

The concentrated collectors have following limitations over flat plate collectors.

1. The concentrated collector absorbs only beam radiation and the diffuse component of radiation cannot be reflected, and hence lost.
2. It requires a sum tracking device for year round operation.
3. It requires additional maintenance to retain the quality of reflecting surface against dirt and oxidation.
4. The solar flux received on the absorber plate is non uniform.
5. Initial cost is high.

Q90. Enumerate different types of concentrating collectors and also list out advantages and limitations.

Answer : May-17, (ME), (R13), Q4(b)

Types of Concentrating Collectors

For answer refer Unit-I, Q20.

Advantages and Limitations

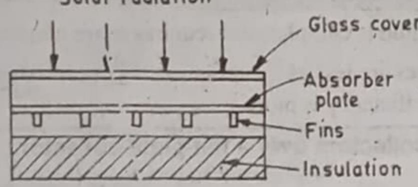
For answer refer Unit-I, Q89.

Q91. Explain briefly about flat plate air collectors.

Answer :

Flat plate air or gas heating collectors are used as solar air heaters. The major difference between the liquid flat plate collectors and air collectors is the design of the passages through which the heat transfer fluid flows.

The schematic diagram of flat plate air collectors is shown in below figure.



Figure

As shown in figure, the air stream is heated by the back side of the absorber plate. To increase the contact surface, the fins are attached to the back side of the absorber plate, thus the heat transfer to the air stream is increased. Heavy insulation usually mineral wool or any other material is provide at the back side of the collector to minimise the heat losses.

The collector should be installed such that it is facing due south at an inclination angle with the horizontal equal to $(\phi_l + 15°)$.

Air is not widely used as heat transport medium in solar collectors but it has some advantages. They are,

1. No freezing and corrosion problems.
2. Small air leaks are not a cause of concern compared to water leaks.

The collectors also have following disadvantages

1. The pump power is high, and larger duct size and higher flow rates are required.
2. The heat transfer from the air to water in a hot water supply system is inefficient.

The applications of a solar air collector solar air heaters are found in,

(i) Drying or curing of agricultural products
(ii) Space heating for comfort
(iii) Seasoning of timber
(iv) Regeneration of dehumidifying agents
(v) Curing of industrial products like plastics.

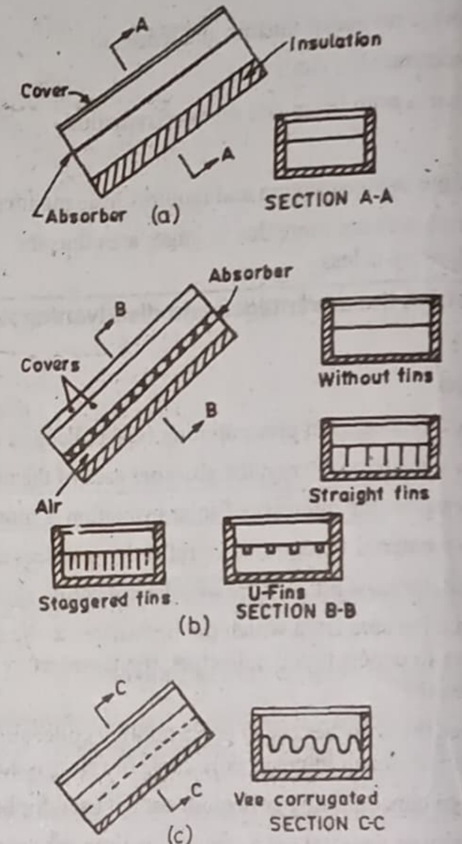
Q92. Explain briefly about following,

1. **Non-porous absorber plate type collectors**
2. **Collectors with porous absorber.**

Answer :

1. **Non-porous Absorber Plate Type Collectors**

In non -porous absorber plate type air collector, The absorber plate does not have any pores on it. Thus, the air stream does not flow through the absorber plate. The air stream flow above and or behind the absorber plate and cools it. The air flow above the upper surface of the absorber plate is not recommended as the heat loss due to convection increases.



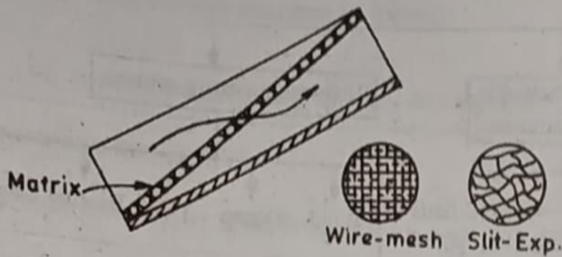
Figure

In these collectors, the transmission of solar radiation through the transparent glass cover and its absorption is similar to that of liquid flat plate collectors.

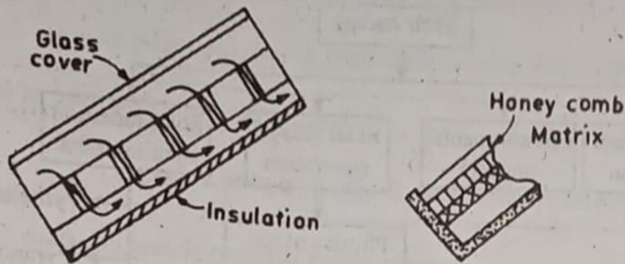
The selective coating are applied over the absorber plate to improve the collection efficiency, provided it involves less cost. Due to low heat transfer rates, for given intensity of solar radiation and temperature conditions, the efficiency is less then the liquid type solar collector. The performance of these collectors can be improved by making the rear surface of the absorber plate rough to promote turbulence and enhance the convective heat transfer coefficient, and also by adding fin to increase heat transfer area.

2. Collectors With Porous Absorbers

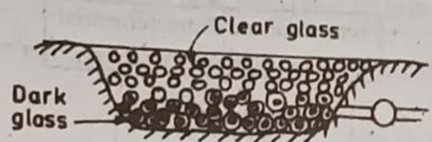
In these type of air collectors, the absorber has pores, thus the air stream flow through the pores of the absorber plate. Generally, the absorber plate is either a slit or expanded metal or transpired honeycomb matrix or a overlapped glass plate as shown in below figure.



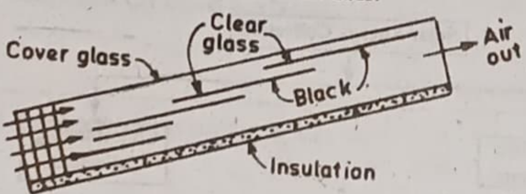
(a) Slit or expanded metal.



(b) Transpired Honey Comb.



(c) Broken bottles absorber.



(d) Over-lapped-glass plate air-heating collector.

Figure

These collector are developed to overcome the draw backs of the non-porous absorber plate in following two ways.

1. Depending on the density of the matrix used, the solar radiation penetrates to greater depths and absorbed gradually.

   The bottom layer of the matrix are much hotter then the upper layers. When the cool air is introduced form the upper surface of the matrix,it is initially heated by the upper layers of the matrix and it gets heated further while travelling through the matrix layers. Since the lower matrix layer are hotter,the heat transfer from the matrix to the air stream is more effective.

   If the matrix porosity and the thickness is not selected appropriately, the collection efficiency may be reduced, since the additional matrix layers beyond optimum thickness will not allow the absorption of solar radiation and further heating of the air stream.

2. The pressure drop for the matrix is usually much lower than the non-porous absorber.

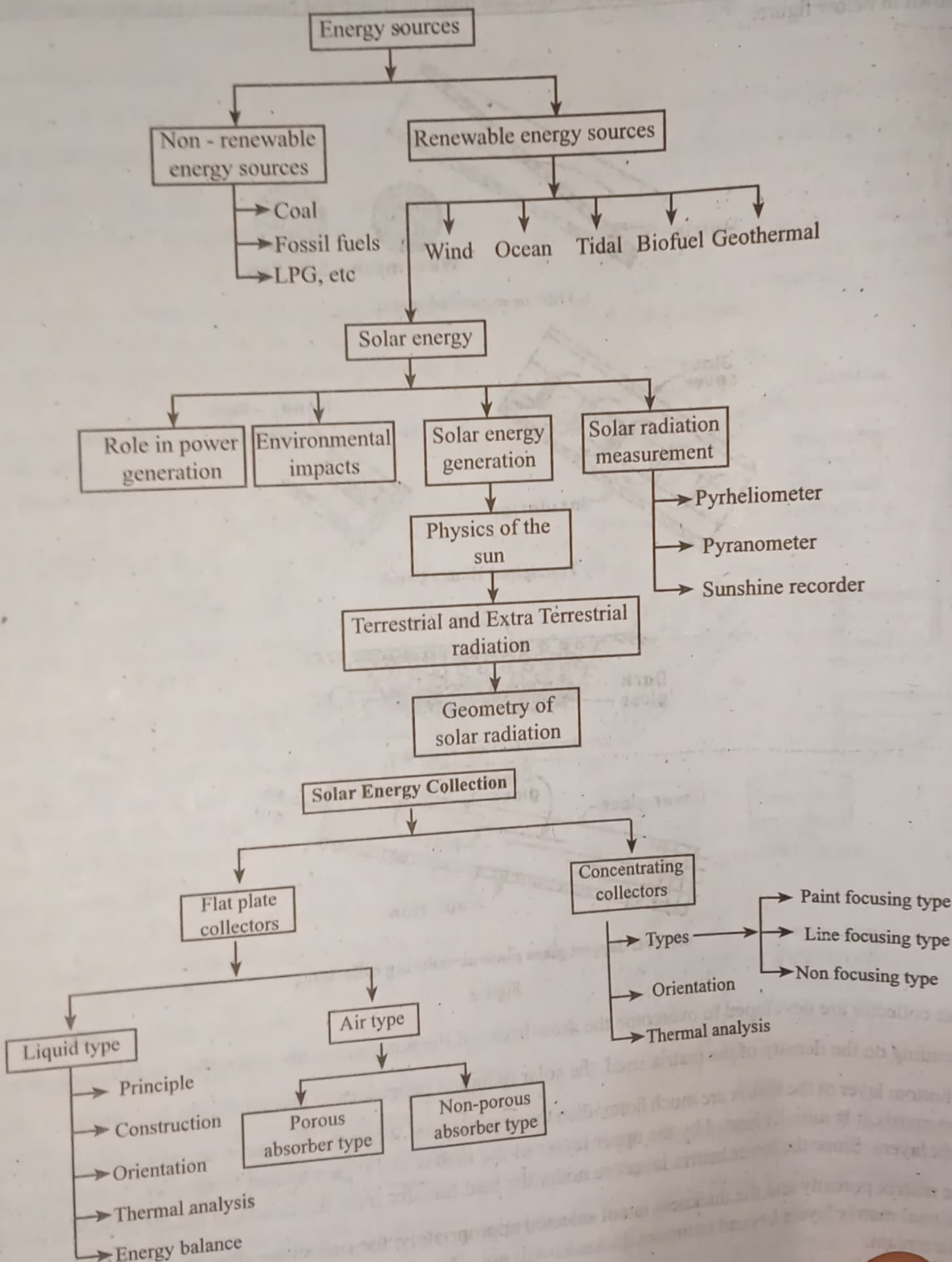
Q93. What is the significance of collectors with porous absorbers.

Answer :

April-18, (EEE), (R13), Q4(a)

For answer refer Unit-I, Q92, Topic : Collectors with Porous Absorber.

MEMORY MAP


Energy sources
Non - renewable energy sources
Renewable energy sources
Coal
Fossil fuels
LPG, etc
Wind
Ocean
Tidal
Biofuel
Geothermal
Solar energy
Role in power generation
Environmental impacts
Solar energy generation
Solar radiation measurement
Pyrheliometer
Pyranometer
Sunshine recorder
Physics of the sun
Terrestrial and Extra Terrestrial radiation
Geometry of solar radiation
Solar Energy Collection
Flat plate collectors
Concentrating collectors
Types
Paint focusing type
Line focusing type
Non focusing type
Orientation
Thermal analysis
Liquid type
Air type
Principle
Construction
Orientation
Thermal analysis
Energy balance
Porous absorber type
Non-porous absorber type