R18

MODEL PAPER

Jawaharlal Nehru Technological University Hyderabad

B.Tech. IV Year II Semester Examination

NON-CONVENTIONAL SOURCES OF ENERGY

Time: 3 Hours | Max. Marks: 75

Note: This question paper contains two **Parts A** and **B**.

Part A is compulsory which carries **25 marks.** Answer **All** questions in **Part A**.

Part B consists of 5 Units. Answer any one full question from each unit. Each question carries **10 marks** and may have a, b, c as sub questions.

Solutions

PART-A

1. (a) Differentiate conventional and non conventional energy sources. (Unit-1 / Q5)
   (b) Explain electromagnetic energy storage method. (Unit-2 / Q4)
   (c) What is anaerobic digestion? (Unit-3 / Q4)
   (d) What are the different types of geothermal resources? (Unit-4 / Q2)
   (e) State the limitations of Direct Energy Conversion. (Unit-5 / Q2)
   (f) What is the need for inclination of flat plate collectors, while concentrators are fixed horizontally? (Unit-1 / Q22)
   (g) Classify different wind turbine rotors. (Unit-2 / Q26)
   (h) List out the different types of biogas plants. (Unit-3 / Q11)
   (i) What are the limitations of tidal power plant? (Unit-4 / Q15)
   (j) What is the principle of operation of MHD generator? (Unit-5 / Q7)

PART-B

2. (a) Explain in brief the world energy scenario along with the alternate energy strategies. (Unit-1 / Q33)
   (b) Explain the importance of orientation in concentrating type collectors and list the different types of sun trackers. (Unit-1 / Q87)

OR

3. (a) What is terrestrial solar radiation? (Unit-1 / Q52)
   (b) Explain the various configurations for the concentrating collectors. (Unit-1 / Q84)

4. (a) Classify different solar energy storage systems and explain them in brief. (Unit-2 / Q39)
   (b) With a neat sketch, explain about solar distillation process. Mention its advantages. (Unit-2 / Q59)

OR

5. (a) Explain about primary, secondary and tertiary winds and how to make use of them for power generation. (Unit-2 / Q70)
   (b) What is the Betz limit and how is it applied to wind turbines. (Unit-2 / Q98)

6. (a) How biomass conversion takes place? (Unit 3 / 020)
   (b) What is a community biogas plant? What are the main problems encountered in its operation? (Unit-3 / 032)

OR

7. (a) Explain the method for converting biomass into ethanol with a neat sketch. (Unit 3 / 024)
   (b) What is meant by energy plantation? What are its advantages and limitations? (Unit 3 / 051)
8. (a) Describe various energy extraction technologies used with hydrothermal resources. (Unit-4 / 076)
   (b) Discuss vapour dominated geothermal plant with a diagram. (Unit-4 / 078)

OR

9. (a) Explain the process of energy conversion from oceans. (Unit-4 / 050)
   (b) Explain briefly about the construction and working of float wave power conversion device. (Unit-4 / 057)
10. (a) Explain the principle of direct energy conversion with examples. (Unit 5 / 014)
    (b) Explain the principle of MHD power generation. (Unit 5 / 023)

OR

11. (a) Describe the operation of a thermionic converter. (Unit-5 / 024)
    (b) Draw the line diagram and explain the working of hydrogen fuel cell. (Unit 5 / 041)

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UNIT 1

PRINCIPLES OF SOLAR RADIATION AND SOLAR ENERGY COLLECTION

Syllabus

Principles of Solar Radiation: Role and potential of new and renewable source, The solar energy option, Environmental impact of solar power, Physics of the sun, The solar constant, Extraterrestrial and terrestrial solar radiation, Solar radiation on tilted surface, Instruments for measuring solar radiation and sun shine, Solar radiation data.

Solar Energy collection : Flat plate and concentrating collectors, Classification of concentrating collectors, Orientation and thermal analysis, Advanced collectors.

LEARNING OBJECTIVES

On completion of this unit, the student shall be able to understand the following concepts,

- Roles and potential of renewable sources
- Solar energy and it's environmental impacts
- Physics of the sun
- Extraterrestrial and Terrestrial solar radiation
- Measuring instruments for solar radiation and sunshine
- Solar radiation data
- Flat plate collectors and concentrating collectors
- Classification and principle of concentrating collectors

INTRODUCTION

Solar energy is the energy produced and radiated uniformly by the sun in the form of electromagnetic waves, which reaches the earth. This energy can be converted directly or indirectly into other forms of energy. For example, production of heat and electricity by using solar energy. Since the sun can radiate the energy for a few billion years at a uniform rate, it is considered as a cheap, clean and abundantly available renewable energy.

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

POINTS TO REMEMBER

- **Commercial or Conventional Energy Sources:** These energy sources include the fossil fuels (Coal, oil and natural gas), hydroelectric power and nuclear power. These represent about 92% of the total energy used in the world.
- **Non-Commercial Energy Sources:** These energy source include wood, animal waste and agricultural wastes. These represent about 8% of the total energy used in the world.
- **Renewable Energy Sources:** The energy sources which are inexhaustible and continuously produced in nature are called renewable energy sources. The various renewable energy sources are.
  1. Solar energy
  2. Wind energy
  3. Ocean energy
  4. Tidal energy
  5. Geothermal energy
  6. Biofuel energy, etc.
- **Solar Energy:** The energy produced and radiated uniformly by the sun in the form of electromagnetic waves, which reaches the earth.
- **Solar Constant:** It is defined as the rate of solar energy received at the top of the atmosphere. "It is the amount of energy collected in unit time on a unit area which is perpendicular to the sun's direction at a mean distance of the earth from the sun".
- **Extraterrestrial radiation:** It is defined as the intensity of sun's radiation outside the earth's atmosphere. It is the "measured solar radiation that would be received in the absence of atmosphere".
- **Terrestrial solar radiation:** It is defined as the intensity of sun's radiation received on the earth surface. It is approximately equal to the 70% of the extra terrestrial radiation.
- **Beam Radiation:** It is the solar radiation received on the earth directly without any absorption or scattering.
- **Diffuse Radiation:** It is the solar radiation received on the earth after its direction has changed by reflection and scattering by atoms and dust particles present in the atmosphere.
- **Solar insolation:** It is defined as the total solar radiation received on a horizontal surface of unit area in unit times.
- **Irradiance:** It is defined as rate of incident energy per unit area of a surface.
- **Sun at zenith:** It is the position of the sun directly overhead.
- **Latitude of Location or Latitude (ϕ):** 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 of earth. By convention, the latitude for northern hemisphere is measured as positive.
- **Declination (δ):** It 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.
- **Hour Angle (ω):** It is the angle through which the earth should be rotated to bring the meridian of the point directly in line with the sun's rays. It is equivalent to 15° per hour.
- **Solar Azimuth Angle (γ_s):** It is defined as the solar angle in degrees along the horizontal east or west of north.
- **Altitude Angle or solar altitude (θ):** It is a vertical angle between the projection of the sun's rays passing through the point and its projection on the horizontal plane.
- **Slope (β):** It is the angle made by the plane surface with the horizontal surface.
- **Day Length:** It is defined as the time interval between the sunrise and sunset.
  (i) The day length is shorter during winter as the sunrises late and sets early.
  (ii) The day length is longer during summer, as the sunrise 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.
- **Instruments used for measuring the solar radiation**
  1. **Pyrheliometer:** This instrument collimates the solar radiation to find out the beam intensity as a function of incident angle.
  2. **Pyranometer:** This instrument is most commonly used for measurements. It measures the total hemispherical solar radiation.
  3. **Sunshine Recorder:** It is an instrument used for measuring the hours of bright sunshine in a day.
- **Collector:** It is a device which collects the solar radiation and then transfers the energy to a fluid that flows in contact with it.

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PART-A SHORT QUESTIONS WITH SOLUTIONS

Q1. Write down various energy sources.

Answer :

The various energy sources include,

Major Sources

(i) Fossil fuels
(ii) Water power of energy stored in water
(iii) Energy of nuclear fission

Minor Sources : Sun, wind, tides, geothermal, ocean thermal energy conversion, fuel cells, thermionic, thermo electric generators, etc.

Q2. What are commercial and non-commercial energy sources?

Answer :

The energy sources are broadly classified into two types. They are,

1. **Commercial Energy Sources :**
   These energy sources include the fossil fuels (Coal, oil and natural gas), hydroelectric power and nuclear power. These represent about 92% of the total energy used in the world.
2. **Non-Commercial Energy Sources :**
   These energy source include wood, animal waste and agricultural wastes. These represent about 8% of the total energy used in the world.

Q3. Define renewable energy sources and list its types.

Answer :

Renewable Energy Sources

The energy sources which are inexhaustible and continuously produced in nature are called renewable energy sources. The various renewable energy sources are,

1. Solar energy
2. Wind energy
3. Ocean energy
4. Tidal energy
5. Geothermal energy
6. Biofuel energy.

Q4. Discuss in brief about the problems associated with renewable energy sources.

Answer :

The problems associated with renewable energy sources are, the energy may not be available at all times and in sufficient quantity. The sun does not shine always and hence, it is not possible to obtain energy during winter and rainy days. The speed of waves required to operate a wave conversion machine is not constant. The wind does not always blow with sufficient velocity which is required to operate the wind mill. Thus, the above aspects necessitates the use of some form of energy storage device.

Q5. List the differences between renewable and non renewable energy resources. July-21, (EEE), (R19), Q1(b)

OR

Differentiate conventional and non conventional energy sources.

Answer : Model Paper, Q1(a)

	Conventional Energy Sources		Non-conventional Energy Sources
1.	Conventional energy sources are also known as non-renewable energy sources, which include coal, petroleum, natural gas, etc.	1.	Non-conventional energy sources are also known as renewable energy sources, which include solar energy wind energy, tidal energy, etc.
2.	Depletion rate is high.	2.	There is no depletion of these resources.
3.	They cause pollution.	3.	They do not cause pollution.
4.	These sources are costly and involves more expenditure.	4.	These sources are comparatively cheaper.
5.	These are difficult to handle.	5.	These are easy to handle.

Q6. What is solar energy?

Answer :

Solar energy is the energy produced and radiated uniformly by the sun in the form of electromagnetic waves, which reaches the earth. This energy can be converted directly or indirectly into other forms of energy. For example, production of heat and electricity by using solar energy. Since the sun can radiate the energy for a few million years at a uniform rate, it is considered as a cheap, clean and abundantly available renewable energy.

Q7. List out the applications of solar energy.

Answer : June-18, (R13), Q1(a)

Applications of Solar Energy

1. Solar water heating
2. Heating and cooling of residential buildings
3. Solar distillation
4. Solar drying of agricultural and animal products
5. Solar cooking
6. Water pumping by solar engines
7. Salt production by evaporation of sea water.
8. Food refrigeration
9. Bio conversion and wind energy production
10. Solar furnaces
11. Solar electric power generation by solar ponds and steam generators heated by solar energy
12. Solar photovoltaic cells, which convert solar energy directly into electricity.

Q8. What is the difference between extraterrestrial and terrestrial solar radiation.

May-18, (R15), Q1(a)

OR

Differentiate terrestrial and extra terrestrial solar radiation.

Answer : April-18, (ME), (R13), Q1(b)

Terrestrial Radiation

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

Extraterrestrial Radiation

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.

Q9. Sketch the short (including visible) and long wave (far infrared) spectral distributions at the top of the atmosphere.

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

Answer :

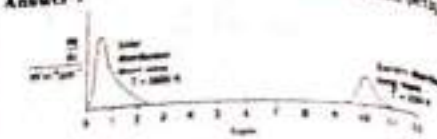

Figure: Short and Long Wave Spectral Distributions at the top of the Atmosphere

Q10. Distinguish between Global Radiation and Diffuse Radiation. Which is applicable during cloudy atmosphere?

Answer : May-18, (R15), Q1(b)

Difference between Global Radiation and Diffuse Radiation

	Global Radiation		Diffuse Radiation
1.	It is radiation from the sun which consists of direct or beam radiation, diffuse radiation and reflected radiation	1.	It is the radiation from the sun after its direction has been changed by reflection and scattering by the atmosphere

Diffuse radiation is applicable during the cloudy atmosphere. On a clear day, the diffuse radiation is about 20% of global radiation, whereas on a cloudy day, it is 100%.

Q11. What is solar constant?

Answer : April-18, (ME), (R13), Q1(c)

Solar Constant

It is defined as the rate of solar energy received at the top of the atmosphere. "It is the amount of energy collected in unit time on a unit area which is perpendicular to the sun's direction at a mean distance of the earth from the sun". The rate of energy received depends upon the distance between the sun and the earth. Since the distance of the sun and its activity vary throughout the year, the rate of solar radiation received by the earth also varies accordingly. Thus, the solar constant is taken as an average from which the actual values vary about ±3%. The standard value for the solar constant given by the NASA (National Aeronautics and Space Administration) is expressed in following three common units.

1. 1.353 kW/m² 1353 W/m²
2. 116.5 langleys/hour or 1165 kcal/m²/hour

   [∵ 1 langley = 1 cal/cm²]
3. 429.2 BTU (British Thermal unit)/ft²/hour.

Q12. Define altitude angle, zenith angle and Azimuth angle.

Answer : May-17, (ME), (R13), Q1(c)

Altitude Angle

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.

Zenith Angle

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.,

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

Azimuth Angle

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

Q13. What is the significance of Zenith angle?

Answer : April-17, (EEE), (R13), Q1(d)

Significance of Zenith Angle

1. The quantity of solar radiation that is reflected or absorbed by earth is based on solar zenith angle.
2. The diffused reflection at high latitudes is higher and this is mainly because of the difference between average zenith angle at equator and poles.
3. The climate on other planets can also be estimated by daytime-average zenith angle.
4. It also helps in determining global radiative forces exerted by aerosols and clouds.

Q14. How do you measure solar radiation on tilted surface?

Answer : [July-19, (R13), Q1(b)] | May-17, (R13), Q1(d)

The total solar radiation incident on any surface comprise 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 surface to the respective values on the tilted surfaces.

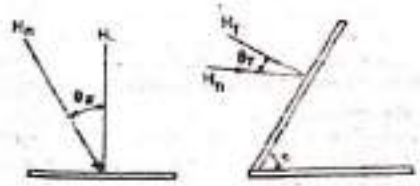

Figure : Radiation on Horizontal and Tilted Surfaces

Q15. What are the different solar radiation measuring instruments.

Answer :

The following two instruments are used for measuring the solar radiation.

1. Pyrheliometer

   This instrument calibrates the solar radiance to find out the beam intensity as a function of incident angle.

   The different pyrheliometers are as follows,

   (i) The Angstrom pyrheliometer
   (ii) The Abbot silver disc pyrheliometer
   (iii) Eppley pyrheliometer
2. Pyranometer

   This instrument is most commonly used for measurements. It measures the total hemispherical solar radiation.

   The different pyranometers are as follows,

   (i) Eppley pyranometer
   (ii) Yellot solarimeter
   (iii) Moll-Gorczy beski solarimeter
   (iv) Bimetallic actinographs of Rabitzsch type
   (v) Velochine pyranometer

Q16. Why do use pyranometer and its uses?

May-17, (ME), (R13), Q1(b)

OR

Write short notes on pyranometer.

Answer :

Pyranometer is an instrument used for the measurement of the total or global radiation over a hemispherical field of view. To measure the diffuse component of radiation, the beam radiation is prevented from falling on the sensor by attaching a shading ring over the sensor. On the black surfaces of the shading ring, the hot junctions of the thermopile are attached. And, the cold junctions of the thermopile are placed in location such that they do not receive the radiation. Because of the temperature difference between the black and the white surfaces, an electrical output voltage in the range of 0 mV to 10 mV is generated, which indicates the intensity of the solar radiation. This output can be obtained on a strip chart or on a digital print out over a period of time, which represents the measure of global radiation.

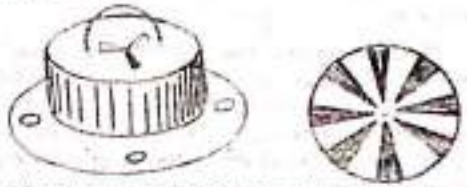

Figure : Pyranometer with Alternate Black and White Sensor

Q17. Write short notes on collector.

Answer :

A collector is a device which collects the solar radiation and then transfers the energy to a fluid that flows in contact with it. There are usually two types of collectors. They are,

(i) Flat plate collectors

(ii) Concentrating collectors.

Q18. Give classifications of solar collector.

Answer : June-18, (R13), Q1(c)

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

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

   These are sub classified into two types.

   (i) Liquid heating collector

   (ii) Air heating collector

2. Concentrating collectors.

   These are sub-classified into two types as follows,

   (i) Focussing type collectors

   (a) Point focussing

   (b) Line focussing

   (ii) Non-focussing type collectors

   (a) Mirror-boosted flat plate collectors

   (b) Compound parabolic collectors (CPC)

Q19. Write short notes on concentrating collectors.

Answer :

Concentrating collectors are also known as focusing type solar collectors. These collectors make use of optical devices such as mirrors and lenses to converge or concentrate the sun's rays on the absorber and the fluid temperature can be increased upto 500°C.

The area of solar radiation received is much higher than the area of absorber, thus the efficiency is high.

These collectors can concentrate the beam radiation, since it has a unique direction and travels in a straight line. Whereas, the diffused component of the radiation cannot concentrated, since it has no specific direction and does not satisfy any optic laws. The collector is attached to a sun tracking device, so that it faces the sun always and absorbs maximum possible solar radiation. This results in better performance.

Q20. Give the classification in concentrating collectors.

[July-18, (R15), Q1(c)] | May-17, (R13), Q1(c)

OR

Classify the concentrating collectors.

April-18, (R13), Q1(c)

Answer :

Concentrating Collectors 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 (parabolodal collector)

2. Non focusing type collector

   (i) Flat plate collector with adjustable mirrors

   (ii) Compound parabolic concentrator (CPC)

Q21. What are the advantages of concentrating collectors?

April-18, (R13), Q1(c)

OR

Discuss how the concentrating collectors are advantages over flat plate collectors.

Answer : June-18, (R13), Q1(c)

The advantages of concentrating collector are as follows

1. The area receiving the solar radiation is higher
2. High temperatures of working fluid can be achieved
3. High temperature thermal energy is obtained
4. Thermal heat losses are less
5. These collectors are economical

Q22. Explain the reasoning for deciding the orientation of a flat plate solar collector.

May-18, (R13), Q1(c)

OR

What is the need for inclination of flat plate collectors, while concentrators are fixed horizontally?

Answer : [May-18, (R15), 4(b)] | Model Paper, Q1(c)

Generally the flat plate collectors are fixed in one position and do not track the sun. Thus, it is important to decide the amount of tilt should be given to the collector so that it receives the maximum possible solar radiation throughout the year.

The optimum tilt angle (β) is equal to the latitude (ϕ) of the location where the flat plate is installed. The optimum tilt angle would be (ϕ + 10°) to (ϕ + 15°) during the winter and (ϕ − 10°) to (ϕ + 10°) during the summer.

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Q23. The selective coating on absorber plate of solar flat plate collector reduces the heat losses. Analyze the reasons with the heat transfer properties.

Answer :

The heat losses in solar flat plate collector reduces due to selective coatings on absorber. The main factors responsible to reduce losses are as follows,

1. High absorbance ability for shortwave radiation (i.e., < 2.5 μm).
2. Low emittance property for long wave radiation (i.e., > 2.5 μm).
3. It reflects thermal radiation.
4. It can withstand temperature and humidity variations.
5. It is more adhesive and can resist atmospheric oxidation, corrosion, etc.

Q24. What are the factors affecting the performance of a flat-plate collector.

Answer :

The following factors affect the performance of a flat plate collectors.

1. Incident solar radiation
2. Number of cover plates
3. Selective surface
4. Fluid inlet temperature
5. Spacing between absorber plate and glass cover
6. Dust on cover plate
7. Tilt of the collector.

Q25. How do you classify air heaters.

Answer :

The air heaters are classified into two types. They are,

1. **Non Porous Absorber Plate Type**

   In this type air heaters, the air stream does not flow through the absorber plate, and it can flow above or below the absorber plate.

2. **Porous Absorber Plate Type**

   In this type of air heaters, the air stream flows through the absorber plate. Generally, the absorber plate can be either slit and expanded metal or transpired honeycomb matrix or over - lapped glass plate.

Q26. What are the drawbacks of the non-porous absorber plate.

Answer :

The main drawbacks of the non-porous absorber plate are as follows.

1. All the incoming solar radiation is should be absorbed over the projected area from a thin layer over the surface of the thickness in the order of few microns. The radiative losses from the absorber plate are large without the use of selective coating. Thus, the collection efficiency cannot be improved.
2. The pressure drop along the duct formed between the absorber plate and the heat insulation also reduces the performance of these collectors. Addition of fins or enlarged corrugations to increase the heat transfer between the absorber and air stream results in further pressure drop across the collector. Therefore, more fan power is required to maintain the same air flow rate through the heater.

Q27. Define optical efficiency. How optical losses in focusing collectors are minimized?

Answer :

Optical Efficiency

The combined effect of losses due to radiation or absorption and losses due to geometrical errors in the optical system can be analysed by an efficiency parameter, which is called as optical efficiency.

Therefore, it can be given as,

Optical efficiency, $\eta_{opt} = \rho\gamma(\tau\alpha)$

Where,

$(\tau\alpha)$ – Product of transmittance and absorptance

ρ – Specular reflectance of reflector surface.

γ – Intercept factor.

The optical losses in collectors are minimised by concentrating the flux that is incident on the surface of absorber, on a smaller area.

Q28. Calculate the angle of incidence on a horizontal plane surface of a location whose longitude and latitude are 88°20' E and 22°32' N respectively at 11:00 Hrs (IST) on June 1. The standard IST longitude is 81°44' E.

Answer :

Given that,

Latitude, $\phi_l = 22°32' = 22.53° = 152$

Total number of days, $n = 31 + 28 + 31 + 30 + 31 + 1 = 152$ days

Local standard time, LST = 11 hrs

For horizontal surface, $\beta = 0°$

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

$= 23.45 \sin\left(\frac{360}{365}(284 + 152)\right)$

$\therefore \quad \delta = 22.04°$

The hour angel is given by,

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

$$= 15(12 - 11) = +15°$$

$$\therefore \quad \omega = +15°$$

Then,

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

$$= \cos(22.53)\cos(22.04)\cos(+15) + \sin(22.04)\sin(22.53)$$

$$\cos\theta = 0.9708$$

Then,

$$\theta = \cos^{-1}(0.9708)$$

$\therefore$ Angle of incidence, $\theta = 13.88° \simeq 14°$.

Q29. Determine the sunset hour angle and day length at a location latitude of 35°N, on February 14.

Answer :

Given that,

Latitude, $\phi_l = 35°N$

Day of the year = February

Number of days, $n = 31 + 14 = 45$ days

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

$$= 23.45 \sin\left\{\frac{360}{365} \times (284 + 45)\right\}$$

$$\therefore \quad \delta = -13.62$$

(i) The sunset hour angle is given by, $\omega_s = \cos^{-1}[-\tan\phi \tan\delta]$

$$= \cos^{-1}[-\tan(35°)\tan(-13.62)]$$

$$\therefore \omega_s = 99.76°$$

(ii) Day length, $t_s = \dfrac{2\omega_s}{15} = \dfrac{2 \times 99.76}{15}$

$$\therefore \quad t_s = 13.30 \text{ hrs.}$$

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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), (R19), Q1(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, (EE)), (R16), Q3(a) | Model Paper, Q3(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 1.6×10^7 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, from oceans and lakes, municipal and industrial wastes etc. Using biological methods, these biomass resources are transformed to obtain biofuels like methane, producer gas, ethanol, etc. The energy produced by biomass 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, and 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 20×10^3 MW.

(vii) Ocean Thermal Energy Conversion

The capacity of this resource is more than tidal and 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 the list of 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 electric energy consumption is 702 kWh and that of the world 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 2008 is 144912 MW from different energy sources. The data are as follows,

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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-19, (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 time.
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-19, (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 600 million Indian have not fully switched to modern, clean cooking fuels or technologies.

India faces a range of energy security challenges in the 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 reducing 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.

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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.

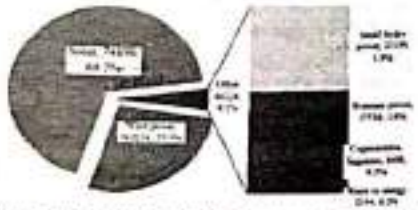


Figure (1) : Estimated potential of Renewable power as on 31-03-2020

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 (122066 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.

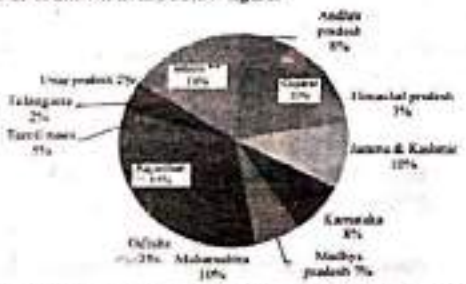


Figure (2) : Geographic distribution of the potential of renewable energy power as on 31-03-2020

Q44. Explain the global potential of renewable energy sources.

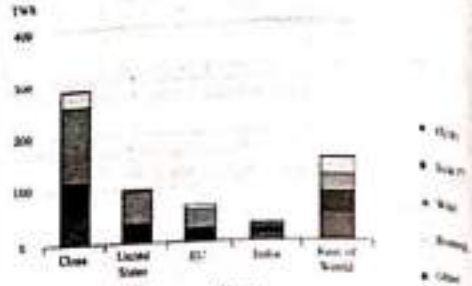
Answer : July-21 (EEE), (R18), Q2(b)

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).

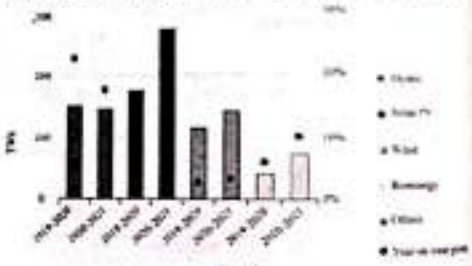
In 2021, renewable electricity generation is set to expand by more than 8% to reach 8300 TWh. Solar PV and wind are set to contribute two-thirds of renewables growth. China accounts for almost half of the global increase in renewable electricity in 2021, followed by the United States, the European Union 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 technology in 2019-2020 and 2020-2021 is shown in below bar chart.



Chart

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

Answer : July-21 (ME), (R15), Q9

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), Q8

Energy Potential Renewable Energy Resources

For answer refer Unit-I, Q43.

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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?

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

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 risk 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 like 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, backup diesel generator, etc. Thus, the total system may contain several pollutants.
6. The solar thermal collectors and roof top photovoltaic (PV) systems may reduce the exposure of people to 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,

$$4({}_1H^1) \rightarrow {}_2He^4 + 26.3\,\text{MeV}$$

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 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 $< \lambda < 0.78$ 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 disk subtend an angle of only 32 minutes on the earth.)

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Q52. How is solar radiation reaching the earth?

May-15, (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. It is approximately equal to the 50% 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.

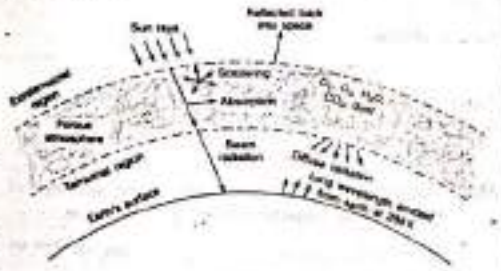

Figure : Solar Radiation Atmospheric Mechanisms

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.

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

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

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.

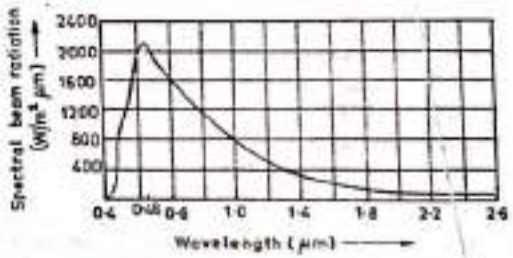

Figure: Spectral distribution of Solar radiation intensity

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 surface. This is known as the albedo of the earth 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/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), P

OR

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

July-19, (R15), Q5

OR

Explain briefly about the 'Solar radiation geometry'

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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.

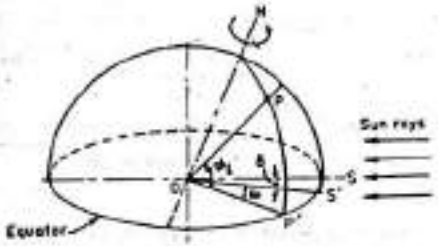

Figure (1) : Latitude ϕ_L, hour angle ω, and sun's declination δ

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.

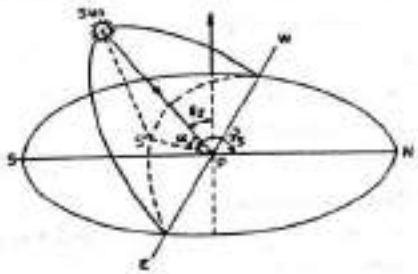

Figure (2) : Sun's Zenith, Altitude and Azimuth Angles

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.

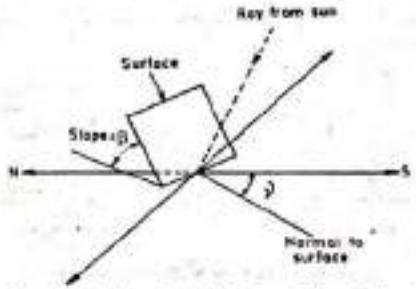

Figure (3) : Surface Azimuth Angle and Slope Defined

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 $66\frac{1}{2}°$ as shown in below figure.

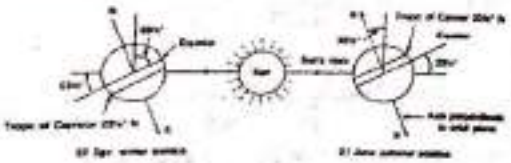

Figure (1) : Tropics and northern hemisphere

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.

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

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.

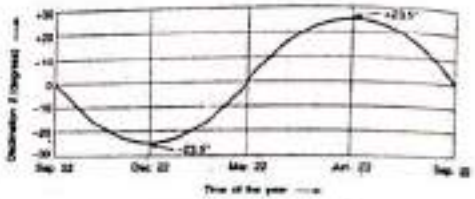

Figure (2) : Variation of Declination Angle

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)

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

$$\text{And } \cos\theta = \cos\theta_z = \sin\alpha \quad \left[\because \theta_z = \frac{\pi}{2} - \alpha\right]$$

3. **Surface Facing South**

For this case, $\gamma = 0$

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

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

4. **Vertical Surface Facing South**

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

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

In terms of θ_z,

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma)$$

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

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-1, Q58, Topic: Hour Angle (ω).

(ii) The sun's Declination

For answer refer Unit-1, 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,

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

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

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.

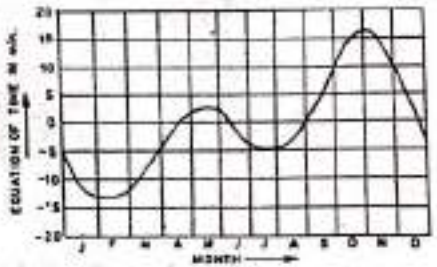

Figure : Graph Equation of Time (E) Correction

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, (R09), (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.

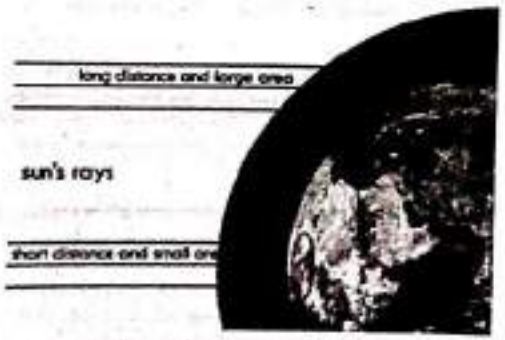

Figure (1) : Variation of Daily Insolation With Latitude

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 is 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-13, (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.

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Q67. How to calculate solar radiation on tilted surfaces?

Answer : [Apr/0-18, (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.

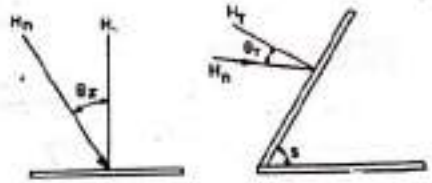


Figure : Radiation on Horizontal and Tilted Surfaces

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

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,

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

From figure,

$$R_b = \frac{H_n \cos\theta_T}{H_n \cos\theta_z} = \frac{\cos\theta_T}{\cos\theta_z} \quad \ldots (2)$$

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

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 denoted 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,

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

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,

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

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,

$$H = H_b R_b + H_d R_d + (H_b + H_d) R_r \quad \ldots (6)$$

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

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), Q3(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.

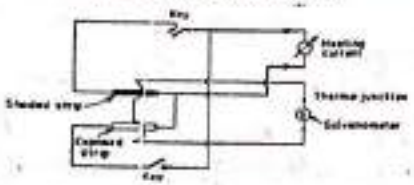


Figure : Electric Circuit for Angstrom Pyrheliometer

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

$$H_{bn} = KI^2$$

Where,

H_{bn} = Direct radiation incident on an area normal to sun's rays

I = Heating current (A)

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

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

July-19, (R15), Q3(b)

OR

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

[Sept.-20, (R18), Q3(b)] April-18, (ME), (R13), Q2(b)]

OR

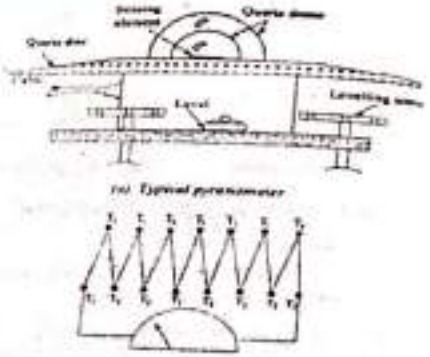
With the help of a neat diagram, explain about Eppley pyranometer.

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 focuses the sun's rays to a point on the card strip.

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

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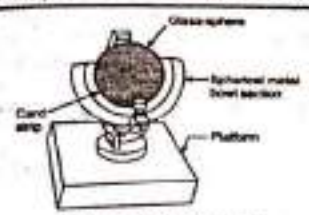

Figure : Sunshine Recorder

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, $\beta = 36°$

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., $\gamma = 0$

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.

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

∴ 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,

$$\cos\theta_r = \cos(\phi - \beta)\cos\delta\cos\omega + \sin(\phi - \beta)\sin\delta$$
$$= \cos(16° - 31°)\cos(22.039°)\cos(15°) + \sin(16° - 31°)\sin(22.039)$$
$$= \cos(-15°)\cos(22.039°)\cos(15°) + \sin(-15°)\sin(22.039°)$$
$$= 0.864 + (-0.697)$$
$$\cos\theta_r = 0.767$$
$$\theta_r = \cos^{-1}(0.767)$$
$$\theta_r = 39.914°$$

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

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.

April-18, (EEE), R13, Q8(a)

Answer :

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,

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

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

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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?

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

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.

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

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

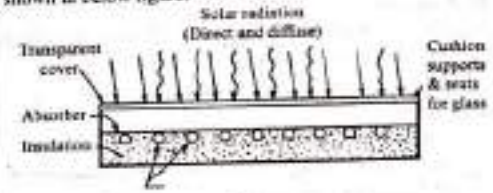
Briefly explain flat plate collector with neat diagram.

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, aluminum or steel. Some time plastic plates are 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 tailor 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 to 1 mm. The materials used for absorber plate are copper steel, aluminum 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 insulation 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 focusing 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.

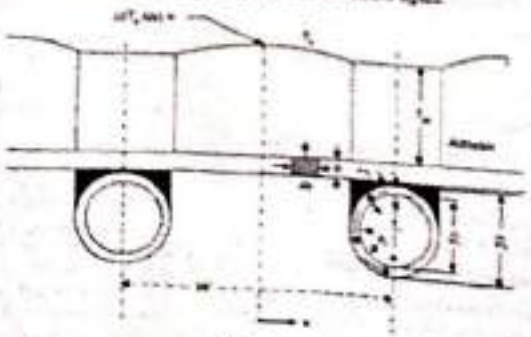
Applications

- 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 :

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



Figure

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

i.e.,

W – Length of the absorber plate between tubes

D – Inside diameter of the tubes

D – Outside diameter of the tubes

δ – Thickness of sheets

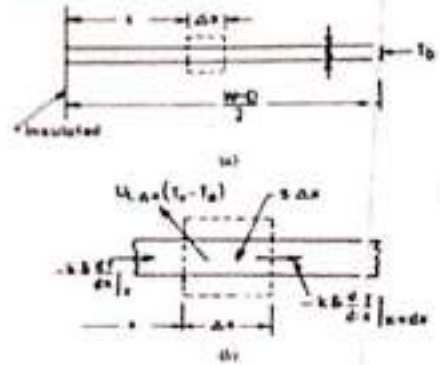
Assumptions

(i) The temperature in the plane (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.



Figure

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

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

$$S\Delta x - U_L \Delta x(T_p - T_a) + \left[-k\delta\frac{dT_p}{dx}\right]_x - \left[-k\delta\frac{dT_p}{dx}\right]_{x+\Delta x} = 0 \quad \text{...(1)}$$

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

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

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

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

$$\frac{d^2T_p}{dx^2} = \frac{U_L}{k\delta}\left[T_p - T_a - \frac{S}{U_L}\right] \quad \text{...(2)}$$

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

1. $\left.\frac{dT_f}{dx}\right|_{x=0} = 0$

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

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

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

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

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

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

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

Then, the equation (6) becomes,

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

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

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,

$$q_{fin\,tube} = -2k\delta \left.\frac{dT_f}{dx}\right|_{x=\frac{W-D}{2}}$$

From equation (8),

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

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

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

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

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

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

Where, $F = \left[\frac{\tanh m\left(\frac{W-D}{2}\right)}{m\left(\frac{W-D}{2}\right)}\right]$, 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,

$$q_{tube} = D\left[S - U_L(T_b - T_a)\right] \quad \text{...(9)}$$

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

$$\therefore \quad q_u = q_{fin\,tube} + q_{tube}$$

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

$$\therefore \quad q_u = \left[(W-D)F + D\right]\left[S - U_L(T_b - T_a)\right] \quad \text{...(10)}$$

The heat from the absorber plate should be transferred to the fluid, and the resistance to this heat transfer comprises of following three 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, $q_u = \dfrac{T_b - T_f}{\dfrac{1}{C_b} + \dfrac{1}{\pi D h_f} + \dfrac{1}{C_w}}$ ...(11)

Where,

C_b – Conductance of the bond

C_w – Conductance of the tube wall

h_f – 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 welding 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 0.31 m °C/W.

From equations (10) and (11),

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

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

W here,

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

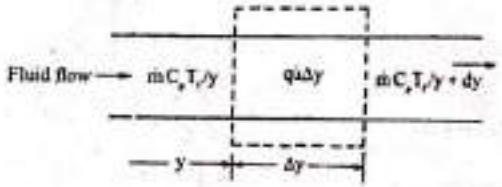
Where,

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

$$\dot{m}C_pT_f\big|_y - \dot{m}C_pT_f\big|_{y+\Delta y} + \Delta y\, q_u = 0 \quad ...(14)$$

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).

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

Where,

$A_c = WL$ – The area of collector

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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),

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

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

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

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, (MC), (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,

$$Q_u = A_c[IR(\tau\alpha)_{eff} - U_L(T_p - T_a)]$$

Where,

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

A_c – Area of the collector, (m^2)

IR – 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,

$$A_c[IR(\tau\alpha)_b + IR(\tau\alpha)_d] = Q_u + Q_L + Q_s$$

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.

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

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 focusing type concentrating collector. The working principle of this type of collector is shown in below figure.

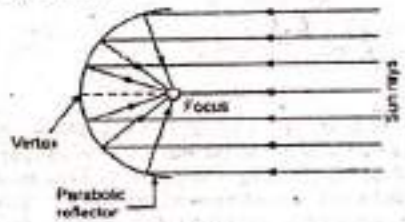

Figure (1)

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.

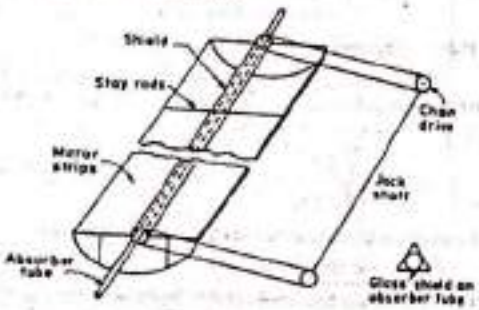

Figure (2)

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.

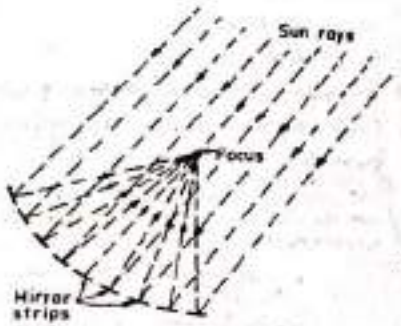

Figure (3)

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.

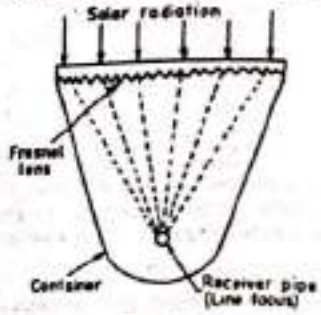

Figure (4)

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.

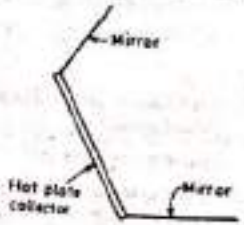

Figure (5)

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.

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5. **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.

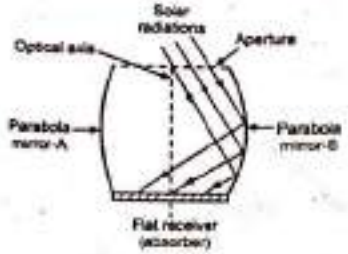


Figure (6)

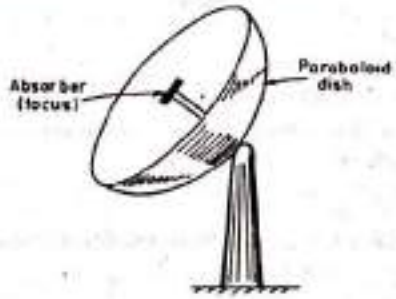
As shown in figure, the absorber plate or receiver is a flat surface parallel to the aperture joining of two foci of the reflecting mirrors. This collector has a large acceptance angle and it has to be adjusted intermittently. The solar radiation in the central region of the aperture reach the absorber 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, (ECE), (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,

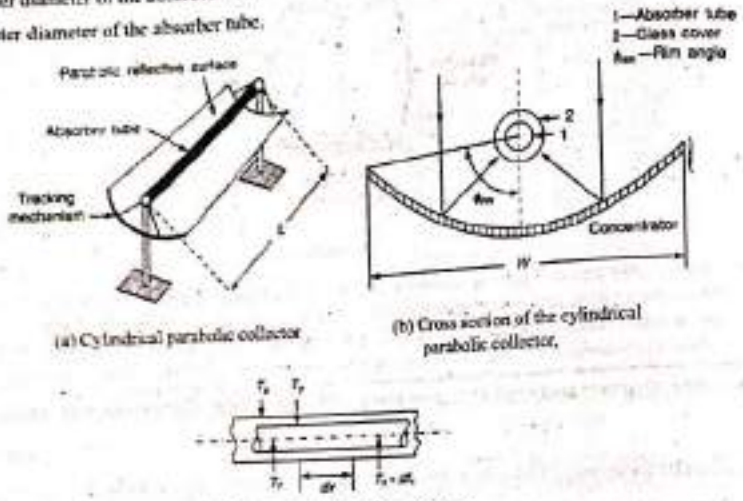
w – Width of concentrator or aperture.

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,

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

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

Beam radiation normally incident on aperture is $I_b R_b$

Under steady state condition,

$$dQ_u = [I_b R_b (W - D_o)\rho r(\rho\alpha)_b + I_d R_d D_o (\tau\alpha)_d - U_l \pi D_o (T_p - T_a)]dx$$

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

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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 radiation 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 retadiation.

The absorbed radiation flux be given by,

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

Then, equation (2) can be written as,

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

The usefuel heat gain rate can absobe 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,

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

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

$$F' = \frac{1}{U_o\left[(1/U_l) + (D_o/D_i h_f)\right]}$$

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

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

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

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

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

By subtracting the terms on both sides from unity,

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

The useful heat gain rate is given by,

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

or

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

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

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

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

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

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

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_L is given by,

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

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,

$$h_r(T_c - T_a) = \sigma\epsilon_c(T_c^4 - T_a^4)$$

Where,

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

ϵ_c – Emissivity of the surface

T_c – Temperature of the radiant surface

Then,

$$h_r = \sigma\epsilon_c(T_c + T_a)(T_c^2 - T_a^2)$$

Assume, $T_c = T_a$ and $\bar{T} = (T_c - T_a)/2$

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

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, Q3(b))

Concentrating collectors are also known as focusing type solar collectors. These are a special type of flat plate collector 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.

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Q88. Compare focusing collectors with flat plate collectors. May-19, (R15), Q1(c)

OR

Differentiate between flat plat collectors and concentrating collectors?

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

	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.

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

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 is 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 sun 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

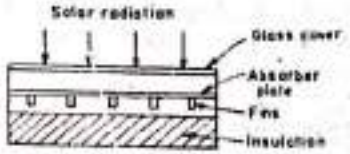
For answer refer Unit-I, Q89.

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 (ϕ + 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.

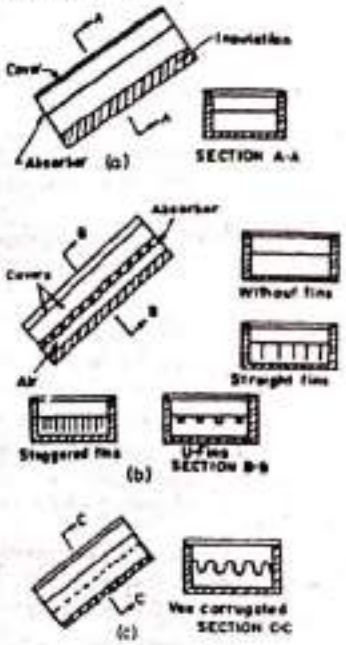
Q92. Explain briefly about following,

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.

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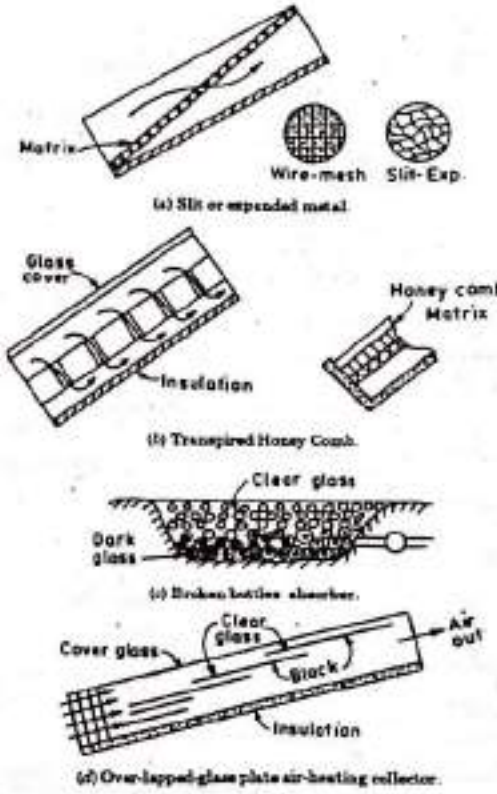
2. **Collectors With Porous Absorbers**

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.



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.

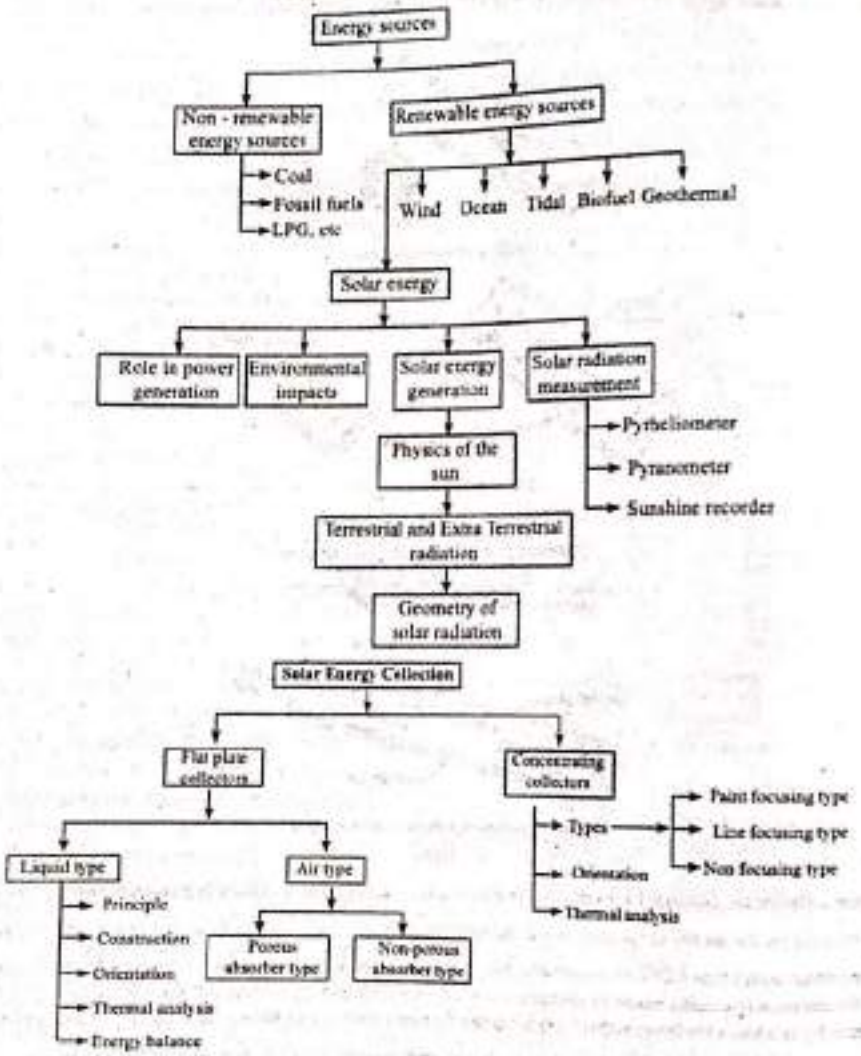
2. The pressure drop for the matrix is usually much lower than the non-porous absorber.

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



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FREQUENTLY ASKED QUESTIONS AND IMPORTANT QUESTIONS

Q1. Explain the potential of renewable energy sources in India.

Ans: Refer Q43. [July-21, (ME), (R16), Q2(b) | Dec.-20, (R16), Q1 | July-19, (R15), Q3(b) | April-18, (ME), (R13), Q3(a)] — 4 TIMES

Q2. How is solar radiation reaching the earth?

Ans: Refer Q52. [May-19, (R15), Q1(a) | May-17, (EEE), (R13), Q3(a) | June-18, (R13), Q2(a) | May-17, (ME), (R13), Q3(a)] — 4 TIMES

Q3. Explain the working of sunshine recorder with the help of a neat sketch.

Ans: Refer Q71. [July-19, (R15), Q3(a) | May-19, (R15), Q2(b) | June-18, (R13), Q1(b) | April-18, (R13), Q3(b)] — 4 TIMES

Q4. Give the classification in concentrating collectors.

Ans: Refer Q20. [July-19, (R15), Q1(c) | May-17, (EEE), (R13), Q1(c) | April-18, (EEE), (R13), Q1(c)] — 3 TIMES

Q5. With the help of a neat diagram, explain about Pyranometer.

Ans: Refer Q70. [July-19, (R15), Q2(b) | Sept.-20, (R16), Q3(b) | April-18, (ME), (R13), Q2(b)] — 3 TIMES

Q6. What is the difference between extraterrestrial and terrestrial solar radiation.

Ans: Refer Q8. [July-19, (R15), Q1(a) | April-18, (ME), (R13), Q1(a)] — 2 TIMES

Q7. How do you measure solar radiation on tilted surface?

Ans: Refer Q14. [July-19, (R15), Q1(b) | May-17, (R13), Q3(a)] — 2 TIMES

Q8. What are the advantages of concentrating collectors?

Ans: Refer Q21. [April-18, (ME), (R13), Q1(c) | June-18, (R13), Q5(a)] — 2 TIMES

Q9. Explain the reasoning for deciding the orientation of a flat plate solar collector.

Ans: Refer Q22. [May-19, (R15), 1(d) | May-19, (R15), 4(b)] — 2 TIMES

Q10. Explain with constructional features of solar flat plate collector for efficient conversion.

Ans: Refer Q80. [May-19, (R15), Q4(a) | May-17, (EEE), (R13), Q5(a)] — 2 TIMES

Q11. Explain briefly about various parameters of solar energy reaching the earth surface.

Ans: Refer Q58. [Dec.-20, (R16), Q4 | July-19 (R15), Q2(a)] — 2 TIMES

Q12. How to calculate solar radiation on tilted surfaces?

Ans: Refer Q67. [April-18, (EEE), (R13), Q3(a) | May-17, (ME), (R13), Q3(a)] — 2 TIMES

Q13. Explain the working of Pyrheliometer with the help of neat sketch.

Ans: Refer Q69. [June-18, (R13), Q2(b) | April-14, (R09), Q1b)] — 2 TIMES

Q14. 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. 2 Marks

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

Ans: Refer Q76.

Q15. With the help of a neat diagram, explain the working of a concentrating collector. 2 Marks

[July-19, (R15), Q4(a) | May-13, (R09), Q2(a)]

Ans: Refer Q84.

Q16. Compare focusing collectors with flat plate collectors. 2 Marks

[May-19, (R15), Q1(c) | May-17, (EEE), (R13), Q4(a)]

Ans: Refer Q88.

Q17. Differentiate conventional and non conventional energy sources. Important Question

Ans: Refer Q5.

Q18. Describe briefly the world energy scenario. Important Question

Ans: Refer Q33.

Q19. Briefly explain the global and Indian energy scenario. Important Question

Ans: Refer Q35.

Q20. What is Solar constant and Explain terrestrial and extra terrestrial solar radiation? Important Question

Ans: Refer Q54.

Q21. Differentiate between :

(a) Primary and Secondary Sources

(b) Renewable and Non-Renewable Source

(c) Conventional and Non-Conventional.

Ans: Refer Q31. Important Question

Q22. Discuss the global and Indian renewable energy usage and availability. Important Question

Ans: Refer Q45.

Q23. Define :

(i) Direct radiation

(ii) Diffuse radiation

(iii) Solar constant

(iv) Zenith angle

(v) Altitude angle.

Ans: Refer Q59. Important Question

Q24. Explain what is meant by sunshine recorder and solar radiation data? Important Question

Ans: Refer Q75.

Q25. How are solar collectors classified? What are the important features of a solar collector? Important Question

Ans: Refer Q79.

Q26. Derive the equation for solar energy balance and collector efficiency. Write the advantages and disadvantages of flat plate collectors. Important Question

Ans: Refer Q83.

Q27. Enumerate different types of concentrating collectors and also list out advantages and limitations. Important Question

Ans: Refer Q90.

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UNIT 2

SOLAR ENERGY STORAGE AND APPLICATIONS & WIND ENERGY

Syllabus

Solar Energy Storage and Applications: Different methods, Sensible, Latent heat and stratified storage, Solar ponds, Solar applications - Solar heating/cooling techniques, Solar distillation and drying, Photovoltaic energy conversion.

Wind Energy: Sources and potentials, Horizontal and vertical axis windmills, Performance characteristics, Betz criteria.

LEARNING OBJECTIVES

On completion of this unit, student should be able to understand the following concepts,

- Storage methods of solar energy
- Solar ponds and solar applications
- Photovoltaic energy conversion
- Ocean thermal energy conversion
- Tidal energy, wave energy and Mini-hydel power plants
- Sources and potentials of wind energy
- Types of wind turbines
- Horizontal and Vertical axis windmills
- Betz criteria

INTRODUCTION

The solar energy is stored through the following ways,

1. Thermal energy storage
2. Electrical storage
3. Chemical storage
4. Electromagnetic energy storage
5. Mechanical storage.

The air with high velocity moving from high pressure areas to low pressure areas is known as wind. The energy generated from high velocity winds is known as wind energy. It is renewable and inexhaustible source of energy.

The solar energy from the sun falls unevenly on the earth's surface and results in unequal absorption of energy. This uneven distribution of the energy and the earth rotation about its own axis and around the sun causes alternate heating and cooling of the earth's surface, which results in the pressure difference. This leads to the air movement causing winds. Thus, wind energy is also said to be a form of solar energy.

POINTS TO REMEMBER

- **Various methods of storing solar energy:-**

  1. Thermal energy storage
  2. Electrical storage
  3. Chemical storage
  4. Electromagnetic energy storage
  5. Mechanical energy storage

- **Solar pond:** It is a natural or an artificial water body used for the collection and absorption of solar radiation from the sun and its storage as heat.
- **Solar distillation:** It is the process of converting the saline water into distilled or pure water, by the use of solar energy.
- **Solar drying:** It is the process of removing the moisture and preserving the products by utilizing the solar energy.
- **Wind :** The air with high velocity moving from high pressure areas to low pressure areas is known as wind.
- **Wind energy :** The energy generated from high velocity winds is known as wind energy. It is renewable and mechanical source of energy.
- Wind is classified into two types, 1. Planetary or global winds, 2. Local winds.
- Performance of wind mill is defined as Co-efficient of performance (C_p)

$$C_p = \frac{\text{Power delivered by the rotor}}{\text{Maximum power available in the wind}}$$

- The components of wind energy conversion system are,

  i. Aero turbine
  ii. Gearing
  iii. Coupling
  iv. Electric generator
  v. Controller

- **Wind Mill:** It is a device which converts the kinetic energy of the wind into the mechanical energy of the turbine shaft. It is also called as wind turbine.

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PART-A SHORT QUESTIONS WITH SOLUTIONS

Q1. What are the various methods of storing solar energy?

Answer :

Solar energy storage systems can be classified as,

1. **Thermal Energy Storage**
   - (i) Sensible heat storage
     - (a) Water storage
     - (b) Pebble bed storage.
   - (ii) Latent heat storage.
2. **Electrical Storage**
   - (i) Capacitor storage
   - (ii) Inductor storage
   - (iii) Battery storage.
3. **Chemical Storage**
   - (i) Chemical
   - (ii) Thermochemical.
4. **Electromagnetic Energy Storage**
5. **Mechanical Energy Storage**
   - (i) Pumped hydroelectric storage
   - (ii) Compressed air
   - (iii) Flywheel.

Q2. Write short notes on phase change materials of latent heat storage system.

Answer :

In a latent heat storage system, heat is stored in material when its phase changes. Hence, such materials are called phase change materials. The phase change materials may be divided into three types as,

1. **Organic materials**

   The most suitable phase change material under the category of organic materials is paraffin wax. They are suitable for space heating and cooling applications.

2. **Hydrated Salts**

   Hydrated salts such as sodium sulphate decahydrate (Glauber's salt) $Fe(Nu_3)_3 \cdot 6H_2O$ are mostly used for solar applications. Inorganic materials such as $NaNO_3$, NaOH, Ice (H_2O) are used.

3. **Inorganic Materials**

   Properties required for a phase change material are,

1. Melting point should be in the range of working temperature of the application.
2. High latent heat of fusion.
3. Negligible volume change during the phase change.
4. There should not be any considerable supercooling or superheating for the phase change to occur.
5. High thermal conductivity of the material.

Q3. What do you understand by Stratified storage?

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

Stratified storage is a method of storing thermal energy, especially solar thermal energy, in a hot water storage tank having water layers at different temperatures. The warm storage layer of water lies at the top, because the warm water is lighter and the colder storage layers of water lie below the warm layer. In this, only the upper layer of water is to be heated instead of the whole water in the tank, and this warm water is stored so that it can be used whenever required. For efficient storage and working of stratified storage method, the tank should be properly insulated and intermixing of warm and cold water layers is to be reduced. To achieve this, good charging and discharging equipment has to be installed in the setup for supplying and taking the water out of the tank respectively.

Q4. Explain electromagnetic energy storage method.

Answer : [May-17, (ME) (R13), Q1(c)] Model Paper, Q1(b)]

In this, super conducting materials are cooled to temperatures below critical or transition temperature, because they offer zero resistance at such temperatures, and thus can carry strong electric currents with negligible loss. Due to the flow of electric current, an electromagnetic field is produced which can store energy.

Q5. Write short notes on solar cooling.

Answer :

Solar Cooling

Most of the air conditioning and refrigeration systems are utilising solar energy. There are two such systems, that are using solar energy for producing refrigeration effect.

They are,

(i) Vapour compression system

(ii) Absorption system.

(i) Vapour Compression System

In this, a heat pump converts the solar energy into mechanical energy, which in turn drives the compressor. Thus, the compressed vapour refrigerant is condensed and sent to the expansion valve. The expanded refrigerant absorbs the heat from the evaporator at low pressure, to give cooling effect.

(ii) Absorption System

This system uses a refrigerant, that is mixed with the absorbent. The purpose of the absorbent is to dissipate the heat during generation and to absorb it during evaporation. Due to this, the cooling effect is produced.

Q6. What are the merits and demerits of solar furnace?

Answer :

Merits of Solar Furnace

(i) Solar furnace provides instantaneous heating and cooling.

(ii) It provides very high temperatures.

(iii) The heat produced is free from contamination.

(iv) In solar furnace, temperature can be controlled easily by changing the position of material, i.e., in focus.

(v) The various properties can be measured in an open pattern.

(vi) The pattern of furnace is provided by desired atmospheric conditions.

Demerits of Solar Furnace

(i) The cost of the equipment is high.

(ii) Solar furnace can be used only on sunny days and for short period of duration.

Q7. Explain what is meant by Heliostat.

Answer : April-18, (EEE), (R13), Q1(

In central receiving system, there is a central receiver or a boiler mounted on a tall tower using thousands of plane reflectors which absorb all the incoming solar radiation focused on it. These reflectors which can be turned about two axes are called heliostats.

Q8. What are the advantages and disadvantages of solar cooker?

Answer :

Advantages

1. Cost of fuel is eliminated.
2. Solar cookers help in conserving 3 or 4 LPG cylinders per year, if used regularly.
3. No frequent supervision is required. A person can do other things, while cooking the food.
4. It ensures better and nutritious food because of the slow process for cooking.
5. It can be used for long durations.
6. Simple in operation.

Disadvantages

1. It can work only on sunny days.
2. It takes more time to cook the food.

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Q9. What are the main applications of a solar drier?

Answer :

The main applications of solar drier are as follows,

1. Solar drier is applied in drying organic materials like fruits, vegetables, timber etc.
2. It is used for in drying agricultural products.
3. Natural convection or direct type solar drier is used in drying food products.
4. Mixed mode type solar driers are used for drying rice.
5. Solar driers are used in both medium scale and large scale systems.

Q10. What is meant by solar green house?

Answer : May-17, (ME), (R13), Q1(d)

Solar greenhouses are generally used to grow vegetables, fruits and grains based on the management of heat especially in regions with harsh climate. Such greenhouses have the ability to harvest, store and deliver solar energy for times when there is little or absence of sunlight, to sustain plants through colder temperatures. The solar energy enters the greenhouse in the form of light which is absorbed by plants and other surfaces. When the temperature fall, the radiation heat given up by the plants is absorbed by rocks, water and concrete etc., and release the heat to the greenhouse environment.

Q11. What features of solar energy make it attractive for use in irrigation water pump?

Answer :

Irrigation water pump utilizes the power generated by solar energy for pumping water required for irrigation.

There are some features of solar energy that are attractive in utilizing the irrigation pumping. The greatest need for pumping occurs during the summer months, when solar radiation is high.

During periods of low solar radiation, the need of pumping decreases, as there is less vaporisation of water from crops. Hence, an inexpensive pumped storage can be provided in the form of ponds, during the period of requirement.

The major disadvantage of utilizing the solar irrigation system is high capital cost. If the cost of solar pumps can be reduced then solar irrigation could become economical.

Q12. What do understand by photovoltaic conversion?

April-18, (ME), (R13), Q1(d)

OR

Describe solar photovoltaic systems.

Answer :

Solar Photovoltaic Systems

Solar photovoltaic systems are used for converting solar energy directly into electrical energy. This is done by means of a solar cell or a photovoltaic cell.

Solar cell is a device which directly converts solar energy into electrical energy. It uses semiconductor material, which works on the principle of photovoltaic effect under solid state physics. Solar cell is made from a monocrystalline silicon wafer. When photons in sunlight strike the solar panel, they are absorbed by semiconductor material (i.e., silicon), then electrons (–ve charged) are knocked and thereby, separated from atoms and flow through the material to produce electricity. The electrons are allowed to move in a single direction. Solar cell converts solar energy into direct current (D.C) electricity.

Q13. What is solar photovoltaic cell and module?

Answer :

Solar Photo Voltaic Cell

Solar cell is a device which directly converts solar energy into electrical energy. It uses semiconductor material, which works on the principle of photovoltaic effect under solid state physics. Solar cell is made from a monocrystalline silicon wafer.

Solar Photovoltaic Module

A number of photovoltaic cells are connected in series to form a photovoltaic module. Generally, a PV module consists of 36 cells which are very thin silicon wafers. The string of cells are enclosed between a layer of tough glass and layers of Ethyl Vinyl Acetate (EVA) in order to protect them from damage. The whole module is attached to an outer frame which gives strength and facilitates easy mounting on structures. A terminal box is connected to the back of the setup in which the positive and negative ends of solar strings are fixed to terminals by means of welding or soldering. This whole assembly of cells, sealing and terminal box refers to a solar module.

Q14. What is meant by grid connected solar PV system? How the number of units supplied to grid is measured from PV to grid is measured?

Answer : May-17, (EEE), (R13), Q1(f)

Grid Connected Solar PV System

A solar PV power system which is connected to the utility grid for generating electricity is known as Grid connected solar PV system. This power generating system includes solar panels, number of inverters, a power controlling unit and grid connection equipment. This system is different from stand alone power systems as this uses an expensive integrated battery solution. This system is used either for small residential rooftops or for commercial rooftops.

Generation meter and export import metering are used to measure the number of units supplied to the grid. It can also be measured using net metering technique.

Q15. What are direct and indirect gap materials?

Answer : May-17, (EEE), (R13), Q1(i)

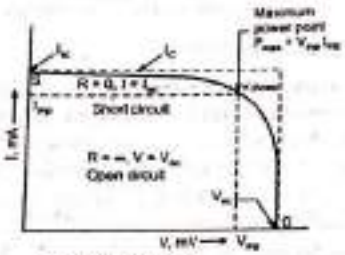
Direct Band Gap Materials: The materials for which maximum of valence band and minimum of conduction band lie at the same value of k are called direct band gap materials. Examples of direct band gap materials are GaAs, mP, Cds. As these materials are made by combining the elements from different columns of periodic table, these are also known as "compound materials".

Indirect Band Gap materials: The materials for which maximum of valence band and minimum of conduction band do not occur at the same value of k are called "indirect band gap materials". Examples of indirect band gap materials are Ge and Si. As these materials are made of simple element from the forth column of periodic table, these are also known as "elemental materials".

Q16. Draw the V-I characteristics of a photovoltaic cell.

Answer : July-19, (R15), Q1(d)

V-I Characteristics of Photovoltaic Cell



V = D.C. output voltage,
I = D.C. current,
I_{sc} = Short-circuit current,
I_c = Current delivered by the cell, and
O, K, S = Open-circuit, Knee, Short circuit points respectively

Figure: V-I Characteristics

Q17. Define the terms wind and wind energy.

Answer :

Wind

The air with high velocity moving from high pressure areas to low pressure areas is known as wind.

Wind Energy

The energy generated from high velocity winds is known as wind energy. It is renewable and inexhaustible source of energy.

Q18. How are winds formed?

Answer :

The solar energy from the sun falls unevenly on the earth's surface and results in unequal absorption of energy. This uneven distribution of the energy and the earth rotation about its own axis and around the sun causes alternate heating and cooling of the earth's surface, which results in the pressure difference. This leads to the air movement causing winds. Thus, wind energy is also said to be a form of solar energy.

Q19. What are the sources of wind?

Answer :

The sources of wind are classified into two categories.

1. **Planetary or Global Winds:** These winds usually blow under the influence of permanent or planetary belts (i.e. higher pressure to lower pressure belts).
2. **Local Winds:** These winds occur in accordance to local pressure gradient conditions. These are originated from local weather conditions and occur for short period of time.

Q20. Mention the various advantages of wind power.

Answer :

Advantages

1. It is readily available in nature and does not cause any pollution.
2. It is clean and mostly available in many offshore, coastal and remote areas.
3. The wind energy obtained is cost effective and reliable for power generation, pumping of water and many applications.
4. It does not produce toxic wastes or green house gases.

Disadvantages

1. Desired winds are available only in few locations away from cities, forests, etc.
2. Wind energy is unsteady, irregular, intermittent and erratic.
3. Direction of wind continuously changes.

Q21. List the applications of wind energy.

Answer :

Applications of wind energy are,

1. Operating irrigation pumps.
2. Operating navigation signals and remote communication.
3. Used for pumped hydro storage of energy.
4. Also used to drive heat pumps.
5. Can be used for space heating and cooling of houses.

Q22. Explain the working principle of windmill.

Answer : May-17, (EEE), (R13), Q1

The wind mill works on the principle of converting kinetic energy of the wind into mechanical energy.

Q23. Write a note on factors influencing wind.

Answer :

Various factors influencing strength and frequency of wind are,

1. Land
2. Weather conditions
3. Vegetative cover
4. Water, etc.

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Q24. Write a short note on wind farm.

Answer :

A group of several hundred individual wind turbines installed at a place to produce electricity is referred as wind farm. It covers an area of several hundreds of square miles. Wind farms can be installed either onshore or offshore. Onshore installations are those installed in hilly or mountainous regions. Offshore installations are those installed in the water bodies. The land between the turbines in onshore farms can be used for agriculture or other purposes. Many largest operational onshore wind farms are located in China, India and United states.

Q25. What are the controlling arrangements required for operating a windmill? List the methods to overcome its fluctuating power generation.

Answer :

The controlling arrangements required for operation of windmill are as follows.

1. Direction control
2. Power control
3. Speed control
4. Pitch control of blades.

Methods used to overcome the fluctuating power generation of wind mill are,

1. On-site domestic unit with battery storage.
2. System with mechanical and solar storage.
3. Intermediate energy conversion with chemical or flywheel storage in medium power range.
4. Power direct feed to main bus-bar.

Q26. Classify different wind turbine rotors.

Answer : [June-18, (R13), Q1(e) | Model Paper, Q1(g)]

The wind turbine rotor are classified as follows.

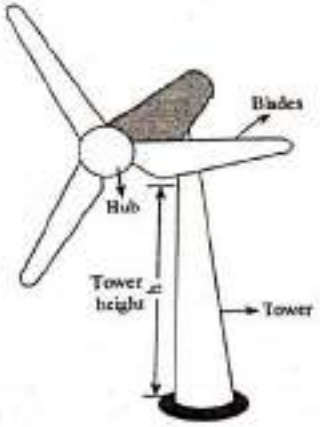
1. Horizontal axis wind turbines (HAWT)
   (i) 2 blades HAWT
   (ii) 3 blades HAWT.
2. Vertical axis wind turbines (VAWT)
   (i) Helical VAWT
   (ii) Savonius VAWT
   (iii) Darrieus VAWT.

Q27. Why is a tall tower essential for mounting a horizontal axis wind turbine?

Answer :

The height of the tower plays a vital role, because the wind increases with height on earth's surface, hence, the tall tower allows access to stronger winds. In some sites at every ten meters height, the wind speed increases by 20% and the output power increases by 34%.

Generally, the tower height varies according to wind turbine models, but generally ranges from 50 ft to 140 ft i.e., the tower height is two to three times the length of the rotor blades for better stabilization and strength.



Figure

Q28. Why horizontal axis wind turbines are preferred over vertical axis wind turbine?

Answer : June-18, (R13), Q1(f)

Horizontal axis wind turbines are preferred over vertical axis wind turbine due to the following advantages.

1. Orientation of blades helps in maintaining stability.
2. Tall tower allows access to stronger wind, thereby increasing the power generation capacity.
3. Tall tower allows placement on uneven land or in offshore locations.
4. It can be installed in forests, above tree line.
5. These wind mills are self-starting.
6. It is cheaper per unit of output, because of higher production volume and larger size.

Q29. List the advantages of the Savonius Rotor wind mill.

Answer :

Advantages

1. Self starting
2. Simple in design and construction
3. Less overall weight
4. Less cost
5. No requirement of yaw and pitch controls
6. Effective power is produced even for low speeds.

Q30. List out three differences between horizontal and vertical axis wind turbine.

April-19, (R13), (R15), Sem

Answer :

Differences between Horizontal Axis and Vertical Axis Wind Turbine

	Horizontal Axis Wind Turbine		Vertical Axis Wind Turbine
1	Efficiency of HAWT is higher as the blades always move perpendicular to the wind	1	Efficiency of VAWT is less compared to HAWT as the blades have straightening motion which creates backblocking against the wind
2	In HAWT, wind strikes the face of the blades at a constant angle independent to the rotation	2	In VAWT, wind direct strikes at continuously angle
3	The hub of tower is tall and thus increases the power output	3	The hub of the tower is short and thus power output is less
4	Transportation of parts is very difficult as it consists of tall towers and long blades	4	Easy transportation of parts as it has short towers
5	Installation cost is high	5	Installation cost is low
6	Complex design	6	Simpler design

Q31. What is the significance of strip chart and magnetic tape?

May-17, (R13), (R15), Sem

Answer :

Significance of Strip Chart

Strip chart is a chart on which a recording device traces the variations of the measuring data over a period of time. This is used in a strip chart recording device which records the graphic data continuously for a variable measuring data. The data be temperature, humidity, flow rates, pressure, etc.

Significance of Magnetic Tape

Magnetic tape is a device that stores data physically. It is generally used for audio and bulky data storage.

Q32. What is meant by gradient height and velocity?

April-18, (R13), (R15), Sem

Answer :

Gradient Height and Velocity

The wind speed at earth's surface is zero and it starts increasing with the increase in height. The wind speed near the earth is reduced because of surface roughness. The rate of change of wind speed with respect to height is called as wind shear or gradient velocity. The height at which the shear forces are reduced to zero is known as gradient height. It is typically about 2000 m.

Q33. Explain what is meant by tip speed ratio.

May-17, (R13), (R15), Sem

Answer :

Tip Speed Ratio

Tip speed ratio is defined as the ratio of the tip speed of the blade to the speed of the entering wind.

It is given by,

$$\lambda_T = \frac{\omega r_T}{v_w}$$

Where,

ω – Speed of rotation of the blade

r – Radius of tour of the turbine

v_w – Speed of the incoming wind

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Q34. What is Betz limit?

April-19, (R13), (R15), Sem

OR

Briefly discuss about Betz criterion.

Answer :

Betz Criterion

The maximum achievable efficiency of the power coefficient of any wind turbine is known as Betz limit. This is also applied for all types of power extractions from tidal and river sources.

In air turbines, the power coefficient (C_p) values are of about 0.4. Power coefficient is also known as maximum efficiency. The loss in efficiency occurs due to viscous drag on blades, swirl imparted to the air flow by rotor and the power losses in the transmission system.

For any ideal wind turbine (Horizontal),

$$\text{Maximum power } (P_{max}) = \frac{8}{27}\rho A V_1^3$$

$$\text{Total power } (P_{total}) = \frac{1}{2}\rho A V_1^3$$

$$C_p = \frac{P_{max}}{P_{total}}$$

$$= \frac{\frac{8}{27}\rho A V_1^3}{\frac{1}{2}\rho A V_1^3}$$

$$= \frac{16}{27}$$

$$= 0.593 \text{ or } 59.3\%$$

The Betz limit shows that the horizontal wind turbine efficiency cannot reach above 59.3%.

Q35. Write the wind power installation capacities in India.

Answer :

Wind power installation capacities in kW as on end of the year 2004 is as follows.

State	2001-02	2002-03	2003-04	2004-05	Total
Andhra Pradesh	92600	0.0	6200	2500	101300
Gujarat	186900	6200	28900	17900	219900
Karnataka	68700	55600	84900	66800	276000
Kerala	2000	0.0	0.0	0.0	2000
Madhya Pradesh	22600	0.0	0.0	5000	27600
Maharashtra	399200	2000	6200	3800	411200
Rajasthan	16100	44600	117800	84700	263200
Tamil Nadu	857600	132800	371200	315900	1677400
West Bengal	1100	0.0	0.0	0.0	1100
Others	500	0.0	0.0	0.0	500
Total	1627300	241200	615200	496500	2980200

Q36. Explain the formation of winds giving out its potential.

Answer : May-19, (R15), 2Sem

Formation of Winds

For answer refer Unit-II, Q18.

Wind Energy Potential

For answer refer Unit-II, Q75, Topic: Status of Wind Energy in India.

Q37. What are the advantages of horizontal-axis wind turbines over vertical-axis wind turbines?

Answer : July-18, (R13) Q10

For answer refer Unit-II, Q90, Topic: Advantages of Horizontal-axis Wind Mills.

PART-B ESSAY QUESTIONS WITH SOLUTIONS

2.1 Solar Energy Storage

2.1.1 Different Methods - Sensible, Latent Heat and Stratified Storage

Q38. Why there is a need in solar thermal energy storage?

Answer :

Need of Solar Thermal Energy Storage

The need of solar thermal energy storage is explained by considering the following cases.

1. In some cases, the energy supplied from the source may be constant. It may consist of a sharp peak load of a very short duration. Hence, in such cases very less amount of energy has to be stored. However, the amount of energy required to be stored is minimum and the energy transfer rate involved must be very high. If there is no provision of thermal energy storage, then a source which provides energy with larger rate is required, in order to meet the sharp demand which increases the total system cost.
2. The energy supplied by a source may vary i.e., the source may have a constant load similar to that of solar energy. In such cases, the amount of energy needed for storage must be stored in day time, rather than in the night time. Because of lack of energy supplied at night. However, the energy source required for such storage must be high, in order to meet the load at day time and also to supply energy at night time.
3. The amount of energy supplied by source and the amount of energy in demand may vary. For example, consider a case where there is occurrence of solar space heating load at night time. In such case, the entire energy is collected during day time and stored to meet the demand at night. However, the amount of energy needed for such storage must be large.
4. In some cases, solar energy available in summer might be required in winter. For such situation, the energy collected during summer goes to storage and is later obtained from storage for winter. This is called as seasonal or long term storage.

Q39. Classify different solar energy storage systems and explain them in brief.

(Part-B, ME), (R13), Q8(b) ; Model Paper, Q4(a)

OR

Explain different methods of storing solar energy.

Answer :

Solar energy storage systems may be classified as below,

1. **Thermal Storage**

Thermal storage can be achieved in two ways, sensible heat storage and latent heat storage.

(i) **Sensible Heat Storage**

For answer refer Unit-II, Q40, Topic: Sensible Heat Storage (without figure).

(ii) **Latent Heat Storage**

For answer refer Unit-II, Q41, Topic: Latent Heat Storage.

2. **Electrical Storage**

Electrical storage can be achieved by capacitors, inductors and batteries.

(i) **Capacitors Storage :** Large amount of electrical energy can be stored in capacitors. Capacitors store electrical energy at high voltage and low current. The expression for the total energy storage is given as,

$$H_{cap} = \frac{1}{2} \epsilon V E^2$$

Where,

V – Volume of the dielectric

ϵ – Constant

E – Electric field strength.

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(ii) **Inductors Storage :** Inductors store electrical energy at low voltage and high current. The expression for energy stored in an inductor is given as,

$$H_{ind} = \frac{1}{2} V \mu H_m^2$$

Where,

μ – Permeability of the material

H_m – Magnetic flux density

(iii) **Battery Storage :** Secondary batteries are used for this purpose because they are rechargeable. Some of such batteries are Pb – acid, Ni – Cd, iron air batteries, etc.

3. **Chemical Storage**

It is achieved by two methods. They are,

(i) **Storage in the Form of Fuel**

In this, the reactant in the battery is generated by a photochemical reaction promoted by solar radiation. This photochemically charged battery discharges electrical energy whenever needed. The photochemical reaction is shown below.

$$2NOCl + \text{Photons} \rightarrow 2NO + Cl_2$$

$$AgCl\,(s) + \text{Photons} \rightarrow Ag(s) + \frac{1}{2} Cl_2$$

$$NO_2 + \text{Photons} \rightarrow NO + \frac{1}{2} O_2$$

$$H_2C + \frac{1}{2} O_2 \xrightarrow{ZnO} H_2O_2$$

(ii) **Thermo-chemical Energy Storage**

In this type of storage, some reversible chemical reactions are used for storage of high temperatures. In forward reaction heat is absorbed and stored in the form of products and heat is liberated in the reversible reaction.

$$A + B \rightleftharpoons AB$$

4. **Mechanical Energy Storage**

This is achieved by three methods.

(i) **Pumped Hydroelectric Storage**

In this, surplus power during off-peak hours is used to pump water from a lower reservoir to a higher reservoir. During peak hours, this pumped water at higher heads is then allowed to flow through a hydraulic turbine, which drives an electric generator.

(ii) **Compressed Air Storage**

In this, air is pumped into a suitable pressurized storage tank and used, when the wind is unavailable. This air drives an air turbine, which in turn drives a generator.

(iii) **Flywheel Storage**

In this, surplus power during off peak hours is stored in the form of mechanical energy in a flywheel. During peak hours, energy stored in the flywheel can be used to operate a generator to produce electricity.

5. **Electromagnetic Energy Storage**

For answer refer Unit-III, Q4.

Q40. Explain about any two methods of solar energy storage.

July-19, (R15), Q8(b)

OR

Discuss in detail any two of the solar energy storage methods.

Answer :

1. **Sensible Heat Storage**

It is a type of thermal energy storage. The material involved in the process undergoes no change in phase, over the temperature zone to which it is subjected in the storage unit. The equation for energy storage with respect to a fixed temperature difference is given as,

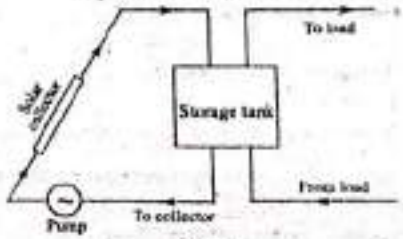
Where,

$$Q_s = (mC_p)_s (T_1 - T_2)$$

T_1, T_2 – Temperature limits of cycle

m – Mass of storage medium

C_p – Specific heat of storage medium



Figure

The system operates between the minimum requirements of the process and the vapour pressure of the liquid.

The capacity of heat storage depends upon the product of C_p and m. Most commonly used materials for storage are,

(i) Water

(ii) Rock, gravel or crushed stone

(iii) Iron shot

(iv) Iron, red-oxide and iron-ore

(v) Refractory materials like silicon oxide, magnesium oxide and aluminium oxide.

2. **Capacitor Storage**

It is one of the methods of electrical storage. Capacitors are employed for the storage of large amount of electrical energy for long periods. The energy stored is given by,

$$H = 1/2\, \varepsilon\, VE^2$$

Where, ε – Constant

V – Dielectric volume

E – Electric field strength.

Electric field strength is dependent on the material and is limited by the breakdown strength (E_m) for the dielectric. The electrical energy, thus stored becomes limited for a material. Mica is the best available dielectric material.

Leakage losses are difficult to avoid with a usage of dielectric, as the conductivity of material is not zero. Also, capacitive storage for long durations of more than 12 hours is uneconomical.

The capacitor accumulates electrical energy at high voltage and low current.

Q41. How solar energy can be stored in the form of thermal energy? Explain.

Answer :

Thermal Energy Storage

By heating, melting or vaporization of a material, the solar energy can be stored and this energy can be made available as heat by reversing the process. Thermal energy storage is used for domestic water and space heating applications, and for the high temperature storage system required for thermal power generation. Thermal storage can be activated by two methods, sensible heat storage and latent heat storage.

1. **Sensible Heat Storage**

For answer refer Unit-II, Q40, Topic: Sensible Heat Storage.

2. **Latent Heat Storage**

In this, energy is stored by heating a material which undergoes a phase change. The energy storage capacity in this case is a function of mass and the latent heat of fusion of the material. Some of the materials used for this purpose are water, Glauber's Salt ($Na_2SO_4 . 10H_2O$), $Fe(NO_3)_2 . 6H_2O$ and Salt Eutectics.

The major advantage of latent heat storage system is that, it is compact in size, compared to a sensible heat storage system. However, the principle of working is complex, as it involves heat transfer between a fluid and storage medium. During the heat extraction process, the storage material first solidifies at the heat transfer surface. Hence, the thermal resistance to the flow of heat keeps on increasing as heat is extracted from the storage. In order to prevent the excess thermal resistance the storage material is placed in long thin containers and the gas is passed through narrow spaces between the tubes. Alternatively, the storage material is placed in the spaces between the tubes and the gas is passed through the tubes.

Figure

Q42. Explain different methods of latent heat storage techniques with line diagrams.

April-18, (EEE), (R13), 5M

Answer :

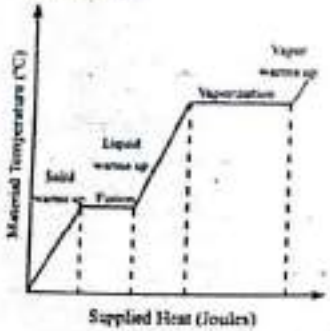
Latent Heat Storage Techniques

In this, energy is stored by heating a material which undergoes a phase change. The energy storage capacity in this case is a function of mass and the latent heat of fusion of the material.

The heat is stored in a material, which undergoes phase transformation during addition and extraction of heat and hence, such materials are called phase change materials.

Various techniques based on the phase changes are,

1. Solid to gas (vapour)
2. Liquid to gas (vapour)
3. Solid to liquid
4. Solid to solid.



Figure

1. **Solid to Gas (vapour) (lathine change)**

The solid to gas (vapour) technique is most difficult and complicated process which cannot be used for storage as there is large volume changes.

2. **Liquid to Gas (vapour)**

The liquid to gas (vapour) technique is also not suitable for energy storage. This is because,

(i) If the system is closed type with constant volume the vapour pressure increases to a large extent during evaporation, which also leads to the increase in temperature which is required for phase change. Thus, storage is not practicable in constant volume.

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(ii) If the system is closed with constant pressure, then there is a large change in the volume during evaporation which makes the system not suitable for storage application.

(iii) If the system is open type with constant pressure (ambient pressure), then the storage material gets evaporated on heat storage. Hence, it cannot be employed for storage application.

3. **Solid to Liquid**

In solid to liquid technique, the storage of heat uses salt hydrates, as storage material. The amount of heat or cold to be stored depends on the storage material selected. In this, storage involves phase change by melting and solidification. When the container used is large enough to fit the phase with larger volume, there will be no significant change in pressure. Thus, both melting and solidification takes place at constant temperature.

4. **Solid to Solid**

The solid to solid technique involves transformation of one crystalline form to other. This includes small changes in volumes which possess small latent heats.

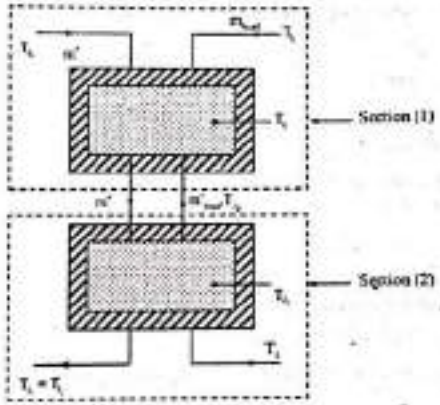
Q43. Draw and elaborate the analysis of a thermally stratified sensible heat liquid storage system.

Answer :

Analysis of Thermally Stratified Sensible Heat Liquid Storage System

It is quite difficult to analyse the thermally stratified tank, as it considers the temperature profile to be solved, as a function of time. Moreover, this issue is not considered practically in one dimensional, since the heat is also conducted through the walls of storage tank.

The analysis of thermally stratified sensible heat liquid storage tank is shown in figure below,



Figure

Thermally stratified heat can be analysed by considering a storage tank with various well-mixed sections at different temperatures and by writing energy balance equation for each section. For example, assume that the storage tank with two well mixed sections having a temperature T_1 and T_2, respectively. The energy balance on these sections is given by,

For section (1),

$$(\rho v c_p)_1 \frac{dT_1}{dt} = \dot{m}c_p\,(T_0 - T_1) - \dot{m}_{load}\, C_p\,(T_1 - T_2) - (UA)_1\,(T_1 - T_a) \quad \text{... (1)}$$

For section (2),

$$(\rho v c_p)_2 \frac{dT_2}{dt} = \dot{m}c_p\,(T_1 - T_2) - \dot{m}_{load}\, C_p\,(T_2 - T_3) - (UA)_2\,(T_2 - T_a) \quad \text{... (2)}$$

The above equations are written based on the assumption that the flow enters the tank at section (1) only. This can be possible only when $T_0 > T_1$. If $T_0 < T_1$ then there is no existence of flow.

Then, by combining the differential equations (1) and (2), the value of T_1 and T_2 can be determined. The above equation can be solved by expressing them in finite difference form and selecting a specific time period. Subsequently, T_1 and T_2 can be obtained from one time period to the other.

Q44. Differentiate between sensible and latent heat storage systems with diagrams.

June-18, (R13), Q4(a)

Answer :

	Sensible Storage System		Latent Storage Systems
1.	Energy stored by heating the material that does not undergo phase change during collection and discharge of energy.	1.	Energy stored by heating the material that undergoes phase change during collection and discharge of energy.
2.	Some of the heat carrying media are water, oils, rocks, pebbles, refractory materials etc.	2.	Some of the heat carrying media are Water, Glauber's salt, $Na_2SO_4.10H_2O$, $TeNO_3.6H_2O$, Salt Eutectics, etc.
3.	The size of storage tank is bigger.	3.	The size of tank and other components as compact.
4.	Energy storage and delivery will be at variable temperature.	4.	Energy storage and delivery are at constant temperature.
5.	Since there is no phase change process, thermal resistance of media will not vary.	5.	Due to phase change process, the thermal resistance of the media may increase.
6.	Sensible heat energy is given as, $Q_s = mc_p\Delta T$ Where, m – Mass flow rate of material, C_p – Specific heat, ΔT – Change in temperature.	6.	Latent heat energy is given as, $Q_L = mL$ Where, m – Mass flow rate of media, L– Latent heat of fusion of fluid.

Q45. What are the advantages of using water and rock as storage medium?

Answer :

Advantages of Water as Storage Medium

1. It is a cheap, easily available and most suitable material to store sensible heat.
2. It has high thermal storage capacity.
3. There is a direct addition and removal of energy from this type of storage by the medium itself, which eliminates the temperature drop between transport fluid and storage medium.
4. Cost of pumping is less.

Advantages of Rock as Storage Medium

1. Rock can be more easily accommodated than water.
2. High heat transfer coefficient is obtained between the air and solid (rock).
3. It can be employed for thermal storage at high temperatures much higher than 100°C where water cannot be used in liquid form.
4. Rock itself acts as a heat exchanger, decreasing the total cost of the system.
5. Rock as storage medium is comparatively cheaper.

2.1.2 Solar Ponds

Q46. Describe the working of a concentration gradient solar pond.

May-18, (R13), Q5(b)

OR

Describe briefly a basic type of solar pond.

May-15, (R09), Q3(a)

OR

Discuss in detail about the mechanism of salt-gradient solar pond with the aid of neat sketches.

Answer :

Solar Pond

It is a natural or an artificial water body used for the collection and absorption of solar radiation from the sun and its storage as heat. Therefore, solar pond is a combination of solar radiation energy collection and sensible heat storage. Solar pond is either a shallow or a deep lake, surrounded by the insulating, absorbing and storing materials.

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Working

A solar pond contains dissolved salts for generating a stable density gradient. It is basically divided into three layers. They are surface convection zone, non-convection zone and the storage zone as shown in figure.

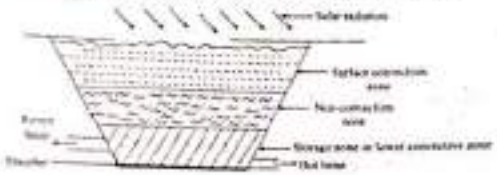

Figure: Solar Pond

The solar radiation from the sun is absorbed by the absorber situated at the depth of the solar pond. This results in rising the temperature of the water at the beneath portion of the pond. The temperature rise is very small. So, for increasing the temperature rise in pond, the water is mixed with salt. The salts concentration will get removed over a period of time because the water at beneath remains hot due to the upward diffusion of salt. The amount of salt required is large. So, it is normally recycled by evaporating the saline water through the surface. The solar energy is extracted by removing the hot water continuously from the bottom of pond and then passing it through a heat exchanger. The fresh water is also added from the top portion of the pond. The mixing and removing of water is carried on three zones of the pond.

The surface convective zone is a low uniform concentration zone. It possesses usually a small thickness and ambient temperature. The central zone is a non-convective zone. This zone usually reduces the heat losses in upward direction and serves as thermal storage zone. The last zone or beneath portion of zone is a storage zone. It is the main thermal storage zone and possesses low convection property. The material used for this zone is LDPE, HDPE, hypalon, etc. Therefore, solar pond can be used for storing the solar energy using the natural or artificial arrangements.

Q47. What are the special arrangements made in solar pond to retain the heat energy content in Solar pond?

May-17, (R09), (R13), Q5(b)

Answer :

The various arrangements made in a solar pond to retain the heat energy content in solar pond are,

1. By maintaining the higher density of salt water at the bottom of the solar pond. Because, this prevents the natural convection of heat transfer between the top and bottom layers of the pond.
2. If dark surface is maintained at the bottom of the pond, then more radiation can be absorbed and that in turn increases the temperature of the bottom layer.
3. The top layer should have low salt concentration and bottom layer should be of high salt concentration. Because, if the same level of concentration is maintained, then the temperature of pond will be equivalent to the atmospheric temperature. Hence extraction of heat is impossible.
4. In a convecting solar pond, the whole solar pond arrangement is placed in a large bag that allows convection, but does not allow evaporation. In order to preserve the heat, bag is coated with black colour at the bottom and a foam insulation is also arranged.
5. The selection of site for a solar pond also effects the heat loss to the ground. If the ground water table for the pond is situated at a minimum depth of 5 m from the surface level, then the heat lost to the ground can be reduced.

Q48. What are the applications of a solar pond?

Answer :

Applications of Solar Pond

The various applications of solar pond are as follows,

1. Heating and cooling of buildings
2. Production of power
3. Industrial process heat
4. Desalination
5. Heating the animal housing, drying crops on farms
6. Heat for biomass conversion

1. **Heating and Cooling of Buildings**

Solar ponds are used for heating even at large latitude stations and also for heating during cloudy days. This is because of having large storage capacity in the lower storage zone of the solar pond. Generally, a solar pond with 100 m in diameter and 1 m deep storage zone is capable of driving an absorption system or a chiller satisfying a required cooling load of 50 houses in a community.

2. **Production of Power**

Solar ponds can be used for generating electricity. This is done by driving a thermoelectric device or an organic Rankine cycle engine in which a turbine is run by evaporating an organic fluid which has a low boiling point. The solar pond for generating electricity can be suitable for the areas, where there is sufficient amount of solar radiation and suitable topography. Even low temperature heat from solar ponds can be converted into electricity. The efficiency of conversion of electricity is limited due to low operating temperatures which are usually of the order 70°C-100°C. Thus, Solar Pond Power Plant (SPPP) requires organic fluids with low boiling points like halo-carbons (such as freons) or hydrocarbons (such as propane).

3. **Industrial Process Heat**

Thermal energy is required in the industries for manufacturing and treatment of materials and goods. Scientists have found the applications of solar pond for supplying process heat in industries as an alternate to oil, natural gas, electricity and coal. Industrial process heat is used in crop drying and in paper industries which is highly economical as compared to oils and natural gases.

4. **Desalination**

The cheap thermal energy can be used to desalinate or purify water for drinking or irrigation. The multi-flash desalination plant below 100°C can be used for producing distilled water. This system is widely used in areas, where there is shortage of pure water and availability of only saline water. It has been found that a solar pond of 0.31 km^2 area can be used to produce about 4700 m^3/day of distilled water. Also, multi-flash desalination plant can be used to produce five times more of distilled water as that of conventional basin type solar still.

5. **Drying Crops on Farms**

In farmland, where there is enough space, low grade heat can be used for drying crops and to heat animal houses.

6. **Heat for Biomass Conversion**

Solar ponds can be used for converting biomass to alcohol or methane.

Q49. With the help of schematic diagram, explain the working of solar pond electric power plant.

Answer : Sept.-20, (R16), Q4(b)

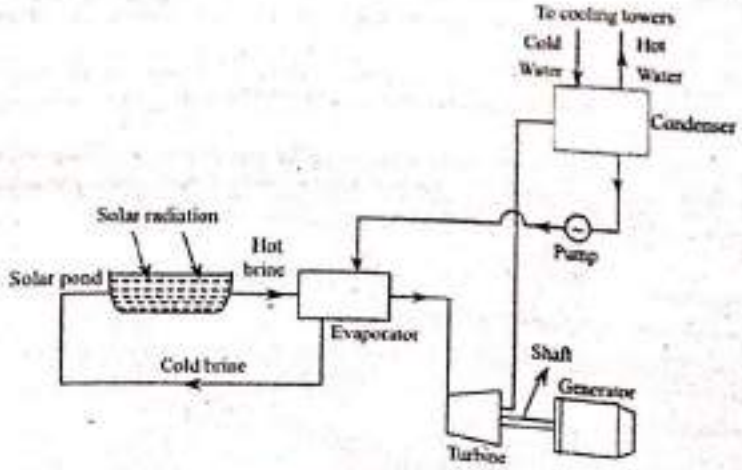

Figure: Solar Pond Electrical Power Plant

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The solar pond is used for lower thermal electrical power production. The solar pond receives and absorbs the direct radiation from sun, thereby collects the heat. It can absorb about 50% of radiation, which drops to 20% due to heat losses. It can collect heat even on cloudy day. When, the temperature of the lower layer of pond reaches above 60°C, then, the generated heat is utilized to run the Rankine cycle heat engine. The organic fluid is vapourized by using the heat from the pond through heat exchanger. This vapour under high pressure is passed through the turbine, where it expands and rotates the blades of the turbine. The vapour then passes through the condenser where it gets condensed by using cold water from cooling tower and the liquid is then pumped back to the evaporator, and the cycle is repeated. The generator set is connected to the turbine through shaft, thus producing electrical energy.

2.2 Solar Applications

2.2.1 Solar Heating/Cooling Technique

Q50. With a neat sketch explain the principle of conversion of solar energy into heat.

Answer : July-21 (EEE), (R13), Q3(b)

The principle involved in the conversion of solar radiation into heat is "Green-house effect".

The gases in the atmosphere that absorb the solar radiation are referred as greenhouse gases (GHG). These include carbondioxide (CO_2), water vapour (H_2O), nitrous oxide (N_2O), methane (CH_4) and chlorofluoro carbons (CFCs).

When the solar radiation strikes the surface of the earth in the form of visible light, ultraviolet light, infrared and other types of radiation, the gases trap the sun's heat and help to sustain life on earth. There is a progressive increase in the greenhouse gases with the industrialization of the planet. These gases trap more amount of solar energy and reflect back less amount towards the outer space, thus making the planet warmer than it used to be. Solar energy generation requires minimum temperature as 30°C-40°C.

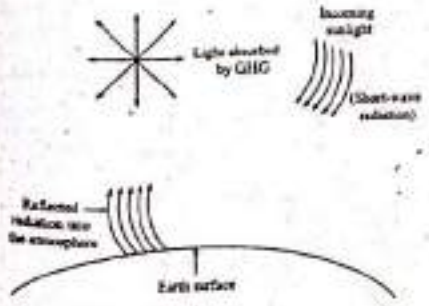

Figure: Green House Effect

Q51. List out the various solar applications.

Answer :

The various solar applications are,

1. Solar thermal applications
   - (i) Water heating
   - (ii) Space heating
   - (iii) Space cooling
   - (iv) Solar distillation
   - (v) Solar drying.
2. Photovoltaic applications:
   - (a) Industrial applications
     - (i) Telecommunication
     - (ii) Cathodic protection
     - (iii) Aircraft applications
     - (iv) Alarm system
     - (v) Defence equipment
     - (vi) Emergency equipment.
   - (b) Electrical power generation
   - (c) Consumer applications such as pocket calculators, watches, clocks, radio, electric fence, toys, etc.

Q52. Explain any two solar heating applications.

Answer : May-13, (R09), Q3(a)

Applications of solar energy are,

1. Solar water heating
2. Solar space heating
3. Solar drying
4. Solar distillation, etc.

1. **Solar Water Heating by Natural Circulation**

For answer refer Unit-II, Q53, Topic: Natural Circulation Solar Water Heating System.

2. **Solar Space Heating by Active Method**

A space heating using solar radiation by active method is carried by using equipment like flat-plate collectors, pump, storage tank, heat exchanger, auxiliary heaters, etc as shown in figure.

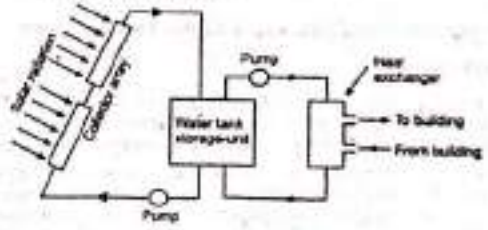

Figure: Space Heating

As the solar radiation falls on the collector, the collector heats the water flowing across it. The hot water is then pumped towards the storage tank. In the storage tank, the hot water is stored. This hot water is pumped to the heat exchanger to transfer the heat to the air circulating in the room. Two pumps are used for pumping the water between the collector and the tank, and between the tank and heat exchanger.

Q53. With a neat sketch explain working of solar water heating systems. April-18, (ME), (R13), Q4(a)

OR

Explain solar water heating system at natural circulation and forced circulation type.

Answer :

Natural Circulation Solar Water Heating System

Construction

It comprises of solar collector insulated storage tank, water circulation tubes, auxiliary heater etc. Usually single glazed flat plate collector is employed. Collector is a welded fabrication of copper sheet and copper tubes. Both sheet and tubes are coated with black coating which has high absorption capacity. Collector is positioned such that it faces the such and its inlet and outlet are connected to top and bottom portion of storage tank respectively. Storage tank is positioned such that its bottom surface is 0.3 m above top of collector. In addition to connections from collector, it also provided with other connections at bottom and top portions in order to allow cold water from mains and hot water for distribution respectively. Auxiliary heater is also installed in storage tank as shown in figure.

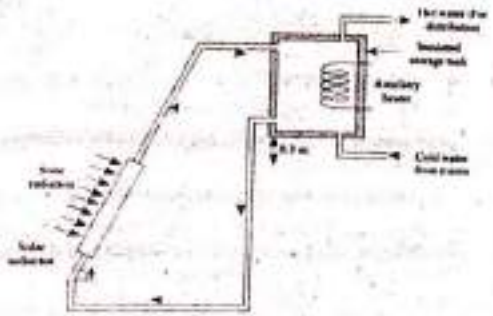

Figure (1): Natural Circulation Solar Water Heating System

Working

In this type of system, water circulation occur due to thermosiphoning or natural convection. As the solar radiation falls on the collector, it absorbs heat and transfers it to the water in the tubes. Then, hot water moves up as its density decreases and enters the storage tank from top portion. Cold water present in the storage tank has higher density and flows to the bottom portion of collector to obtain heating. Difference in densities of hot and cold water is the cause for circulation of water through the storage tank and collector. Whenever it is required, hot water is taken out from top of the tank for distribution and drawn amount of water is replaced by supplying cold water from mains. During day i.e., when sun shines, water circulation continues, but during nights flow direction may reversed and loss of heat to ambient air occurs. In order to avoid this, a level difference of 0.3 m between top of collector and bottom of storage tank is required to be maintained. During cloudy and rainy days, heating is obtained by auxiliary heater which works with electrical input. This type of heater is mostly employed for domestic applications.

Forced Circulation Solar Water Heating System

Construction

Its construction is similar to that of natural circulation water heating system. Only changes in this are in position of storage tank and inclusion of pump in the system. Pump is located in return circuit i.e., on the pipe line connecting lower part of storage tank and bottom header of the collector. As pump enables water circulation, tank can be positioned at more convenient level. This system is also provided with control unit to activate the pump.

Working

When temperature at outlet of collector is 7°C greater than that at storage tank, pump gets activated and pumps the water into collector from storage tank. Whenever it is required hot water is drawn off from top of the tank for distribution. Then, cold water from mains is supplied into storage tank in order to replace the drawn off hot water. Again when collector outlet temperature increases, pump enables water circulation and cycle continues. A non-return valve is required to be positioned below the collector inlet in order to avoid reverse water flow, thereby reducing thermal losses. On cloudy and rainy days, heating system works with help of auxiliary heater which is a back-up for solar heating system. This type of system is mostly suitable for hot water supply in large quantities for hospitals, hotels, offices and industries.

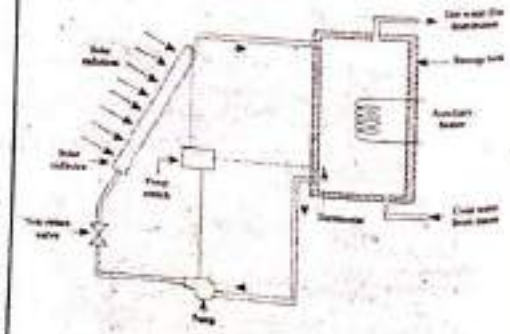

Figure (2) : Forced Circulation Water Heater

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Q54. What are the limitations of using solar water heating systems? May-15, (R09), Q3(b)

Answer :

Limitations of Solar Water Heating Systems

1. It becomes inefficient in cloudy conditions, as the energy obtained from the sun is very less or negligible.
2. Continuous supply of cold water is required for operating the system.
3. Proper insulation should be provided and maintained for the tank, in order to use the water during nights.
4. Scale formation in the collector results in the decrease of system's efficiency.
5. Due to vapour locking phenomenon in pipelines, the supply of hot water ceases.
6. During winter, the system may require additional backup energy for heating water, such as electrical, gas, fuel, etc.
7. These systems are larger in size and hence, difficult to transport.
8. Cost of these systems is high and they are not suitable for indoor installation.

Q55. Compare the performance of solar air heaters with water heating systems. May-19, (R15), Q5(a)

Answer :

Difference between Solar Air Heating and Water Heating Systems

Parameter	Solar Air Heater	Solar Water Heater
Working fluid	Air	Water
Principle process	In this, solar energy is converted to heat energy to increase the air temperature.	In this, solar energy is converted to heat energy to increase the water temperature.
Any usage of chemical for anti-freezing	No	Yes
Heat loss from collector	High	Low
Value of heat transfer coefficient	Low (between absorber plate and air)	High (Between absorber plate and water)
Heat output	Less	Relatively more
Thermal efficiency	Low	High

Q56. Explain the working of solar cooling system with the help of a diagram. July-19, (R15), Q5(a)

OR

Describe the layout and working of a continuous solar cooling system.

Answer : May-17, (ME), (R13), Q5(a)

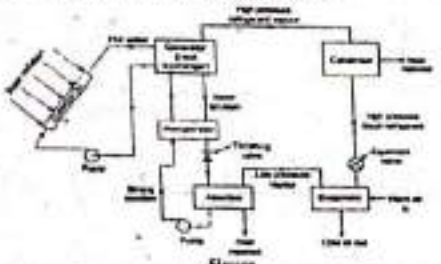
A continuous solar cooling system is similar to a conventional vapour absorption refrigeration system, in construction as well as the operation. The commonly used refrigerant – absorbent solutions in absorption cycle are Lithium bromide – water ($LiBr - H_2O$) and Ammonia – water ($NH_3 - H_2O$). $LiBr - H_2O$ system is used in solar cooling system because of its simplicity and requirement of comparatively lower generator temperature of around 85°C to 95°C which can be achieved by a flat-plate collector.

The main components of a solar vapour absorption cooling system are,

1. Flat-plate collector array
2. Generator or heat exchanger
3. Condenser
4. Evaporator
5. Absorber

Working

In evaporator, heat from the warm air or surroundings is absorbed by the low pressure liquid refrigerant and gets evaporated. This evaporated low pressure vapour then enters the absorber where it readily gets absorbed by the low temperature hot solution releasing the latent heat of condensation due to cooling by the circulating water. Now, this strong solution of LiBr – H_2O from absorber is pumped to the generator by using a pump which increases its pressure. In the generator, heat from the solar collector array is supplied to this high pressure strong solution due to which refrigerant vapour gets evaporated leaving behind a weak solution. This high pressure weak solution is returned to the absorber by passing it through a throttle or pressure reducing valve. And the high pressure refrigerant vapour from absorber is condensed in the condenser to a high pressure liquid refrigerant which is then returned back to evaporator by passing it through a throttle or expansion or pressure reducing valve and the cycle repeats.



Figure

Q57. With the help of a schematic diagram, explain solar passive cooling system.

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

Passive space cooling is one in which no mechanical devices are used and heat transportation occurs by natural processes of convection, radiation and conduction. This can be achieved in several ways such as,

1. Shading
2. Ventilation
3. Evaporation
4. Radiation
5. Ground coupling
6. Dehumidification

1. **Solar Passive Space Cooling by Ventilation**

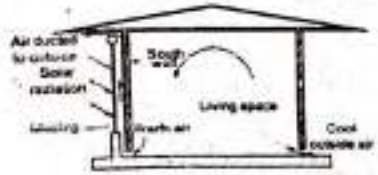


Figure (1) : Solar Passive Space Cooling by Ventilation

This method is effective in places where the outside temperature is moderate and it utilizes the solar 'chimney effect' for air circulation. In this, a glazing is provided on the external side of the south wall with some ducts as shown in figure (1). Solar radiation falling on the glazing heats up the air between the glazing and the interior south wall due to which this heated air rises up and escapes to the outside, drawing the warm air from the room into this space because of natural draught. Now, the cool and fresh outside air enters the room through the bottom air vent provided on the other side of the room and the cycle continues.

2. **Solar Passive Space Cooling by Dehumidification**

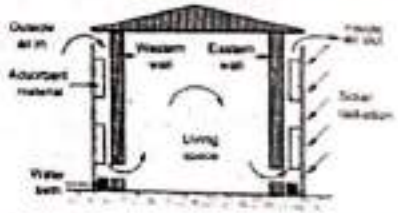


Figure (2) : Solar Passive Space Cooling by Dehumidification

In this method, dehumidification and cooling in the room is carried out by adsorption and evaporation. The walls of a specially designed house in the east and the west are installed with solid adsorbent materials and water baths as shown in figure (2). This method utilizes the concept of chimney effect for air circulation. During morning times, the sun rays fall on the east-wall, which absorbs solar radiation and passes this heat to the air, which rises up as a result, and escapes out. The cool and fresh air is drawn in from the west wall through ducts because of natural draught. This drawn air is dehumidified by a solid adsorbent material and then is cooled evaporatively by water baths. This dehumidified and cooled air then enters the room and the cycle is repeated. During evening times, the sun rays fall on the west wall due to which the flow of air and the functions of east and west walls are reversed to achieve the same cooling effect.

Q58. List the various applications of solar energy. Also explain anyone application, which is economically viable in the present contest.

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

Applications of Solar Energy

For answer refer Unit-II, Q51.

Solar Water Heating

For answer refer Unit-II, Q53.

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2.2.2 Solar Distillation and Drying

Q59. Explain the working of solar distillation process with a neat sketch. June-18, (R13), Q4(b)

OR

Explain the construction and operation of solar still. May-13, (R09), Q3(b)

OR

With a neat sketch, explain about solar distillation process. Mention its advantages.

Answer : Model Paper, Q4(b)

Solar Distillation

Solar distillation is the process of converting the saline water into distilled or pure water, by the use of solar radiation.

For this purpose, a device called solar still is used. The basin type solar still is shown in the figure below.

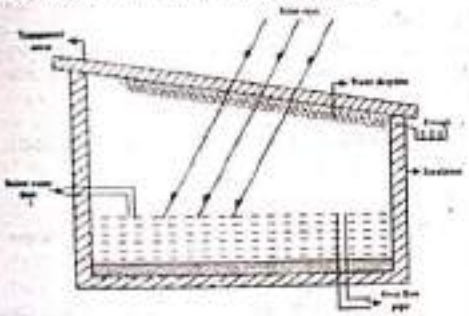

Figure: Basin Type Solar Still

It consists of a basin, which is made shallow and is coated with a black lining called basin liner, an overflow pipe, transparent glass cover, inlet for saline water and trough for collecting distilled water.

In this process, the solar rays are made to pass into the basin through a transparent cover. The saline water flows into the basin through an inlet. The black surface absorbs the heat from solar rays and heats the water. The evaporated water vapour is condensed into water by the inner surface of the glass cover, which is at lower temperature. Then, the distilled water is collected in the trough, as it is directed down by the slope of the cover. The distilled water is then supplied to the storage tank. The excess water is discharged from the basin through an overflow pipe.

Advantages

1. The operation is simple, as no chemicals are used.
2. The amount of energy consumed is less.
3. Highly skilled labour is not required, as the operation is easy.
4. Maintenance cost is low.

Q60. Explain about solar drying

Answer : July-19, (R13), Q4(a)

Solar Drying

It is the process of removing the moisture and preserving the products, by utilising the solar energy. The most basic method of solar drying is that, the crops laid in the form of layers are exposed to direct sunlight. However, in this method, the crops may get contaminated, as they are placed in an open environment. To overcome this, solar dryers are used.

Solar dryers are classified into two types. They are,

1. Natural convection type dryers
2. Forced convection type dryers.

1. **Natural Convection Type Dryers**

These type of dryers does not use any blower and they are simple in operation. Also, the cost of operation is less. A cabinet dryer is an example of natural convection type dryer and is explained as follows.

It consists of a cabinet, which is provided with a transparent cover, perforated trays, and inlet and outlet path for air flow.

The products being dried are kept on the perforated trays. When the solar energy is incident on the cabinet, the rays pass through the transparent cover and get absorbed by the products and cabinet walls. Air flows into the cabinet from the bottom and gets heated, due to the solar heat. Thus, the material is dried and the air passes out from the outlet. The circulation of air takes place naturally.

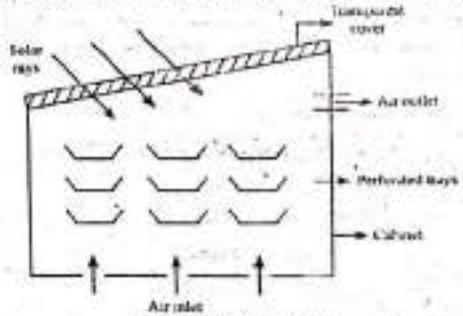

Figure (1) : Cabinet Dryer

2. **Forced Convection Type Dryers**

In this type, a blower or fan, driven by electrical or mechanical energy, is employed for air circulation. An example of this type of dryer is convective dryer, which is used for large scale drying.

It consists of an air heater, blower and a chamber. The blower circulates the air through the air heater. During circulation, the air gets heated due to the incident solar rays. Then, this hot air is supplied into the chamber, where the material to be dried is placed. Thus, the material is dried. These type of driers have very high efficiency.

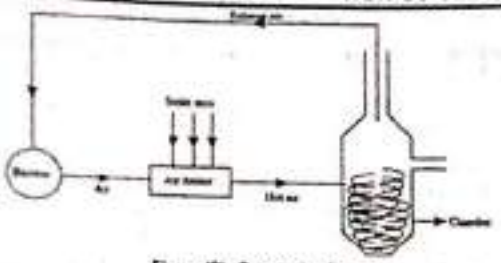

Figure (2) : Convective Dryer

Q61. What is a solar cooker? What are the types of solar cookers? Explain any one in detail.

Answer :

Solar Cooker

Solar cooker is a device which uses solar energy to cook or heat food or drink. The operation cost of these devices is nothing and they do not use any fuels. Thus, these benefits promotes solar cooker in world wide applications.

Thermal energy utilized for cooking consumes a large fraction of the total energy consumption, particularly in rural areas. Different types of fuels such as firewood, coal, cooking gas, dung cakes, kerosene and agricultural wastes are used for cooking purposes. But all these are fossil fuels and are depleting very fast. Firewood causes deforestation. Agricultural wastes, cow dung cakes, cooking gas etc., are more suitable as fertilizers. Hence using solar energy for cooking purpose is a feasible alternative.

Types of Solar Cookers

There are four types of solar cookers. They are,

1. Box type solar cooker
2. Dish type solar cooker
3. Community solar cooker
4. Advanced solar cooker

Box Type Solar Cooker

Construction

The box type solar cooker contains the following elements,

1. Outer box
2. Blackened aluminium tray
3. Double glass cover
4. Reflector mirror
5. Insulation
6. Cooking pots.

Figure (1): Box type Solar Cooker

The outer box is made of fibre glass or aluminium sheet. The insulating material is placed in between the outer cover of the box and the blackened aluminium tray in order to prevent heat loss. Along with direct solar radiation, reflected radiation is also received from an adjustable reflected mirror which is hinged to one side of the box towards the inner side of the box cover. A double glass cover behaves as the window which allows radiation onto the tray. The cooking pots are also coloured black.

Working

The operating principle of a box type solar cooker is shown in figure below.

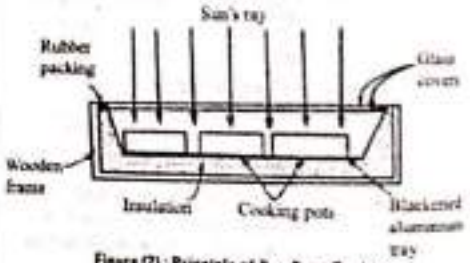

Figure (2) : Principle of Box Type Cooker

The sun rays enter into the solar box through the glass covers (transparent covers) and get absorbed by the blackened aluminium tray. The radiation which is of only shorter wavelength enters into the box as higher radiation wavelength is unable to penetrate through the glass cover. The glass covers provided in the box are two in order to reduce the heat loss. The heat is trapped inside the glass cover because of green house effect. The convective heat loss is reduced by installing a rubber packing in between the upper lid and the box over its whole perimeter.

The box is kept under sun and the rays are absorbed by the blackened metal tray, and the reflecting mirror is adjusted so as to reflect the maximum solar radiation into the box, thereby increasing the temperature of solar box. The cooking pots with the food material inside the solar box get heated up and the food is cooked in certain amount of time depending upon the temperature inside the box. This temperature depends upon the strength of the sun's radiation and the insulation material.

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Q62. What are different approaches of thermal electric conversion system from solar energy?

Answer : April-18, (EEE), (R13), (R09)

Different Approaches of Thermal Electric Conversion System from Solar Energy

1. Parabolic troughs
2. Solar tower (use of heliostats)
3. Solar dishes.

Parabolic Troughs

In this system, many (small) concentrating collectors, each individually track the sun. The collectors are 2-D parabolic troughs (or) 3-D parabolic bowls. Each collector transfers solar heat to a fluid and hot fluid is then gathered from all the collectors at a particular part (i.e., power station). The transfer fluid can be streamed and used directly as working substance in thermal power plant (steam turbine) and this system occupies very large area. The collectors may be parabolic trough type (or) paraboloidal dish type. Several fluids can be used directly (or) indirectly by heat transport i.e., water, air, sodium etc. This system operating at higher temperatures and at higher efficiency, leads to higher material costs and lower life time. Flat plate collectors are restricted due to low operating capacity and less efficiency. Tracking requirement is essential orient towards the sun rays by rotating focal line. The operating temperature is 200°C to 300°C. The plant ranges upto 50 MW.

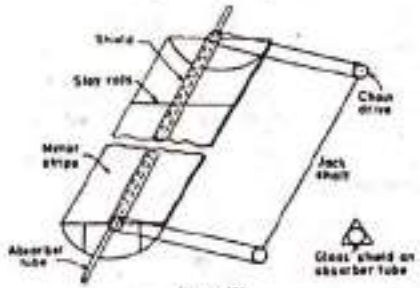


Figure (1)

Solar Tower (Use of Heliostats)

For answer refer Unit-II, Q63.

Solar Dishes

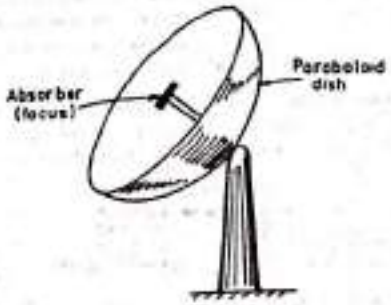


Figure (2) : Solar Dish

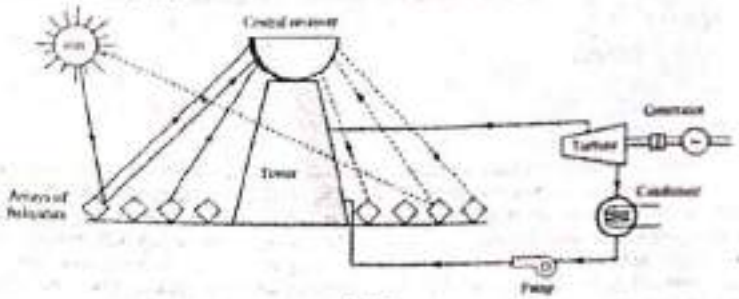
It can be observed from figure that a dish is a single unit with a parabolic reflector. It consists of a heat engine which is mounted on a framework. This entire single unit tracks the sun across the sky. Most of the solar dishes operate at 25 kW power.

Solar dishes are widely used because of their simplicity and efficiency. These dishes have the capability to achieve 30% energy conversion efficiency.

Q63. Give a neat diagram of central tower receiver power plant and explain its operation.

Answer :

Central Tower Receiver Power Plant



Figure

It consists of a central tower with receiver, arrays of mirrors or heliostats, turbine, generator, condenser and a pump.

During the operation, the incident solar radiations are received by the arrays of heliostats, placed around the tower. They reflect the rays on to the central receiver situated at the top of the tower by their tracking control system and these rays are absorbed by the central receiver. The heat obtained from the rays is utilised to heat the water present in the tower and convert it into steam in the receiver. This steam is then used for driving the turbine, which in turn generates electric power, by means of a generator. The exhaust steam from the turbine is condensed in a condenser and is circulated back to the tower, using a pump.

Thus, the power is generated using a central tower receiver power plant and the Rankine cycle is followed.

2.2.3 Photovoltaic Energy Conversion

Q64. Explain the mechanism of photoconduction in a PV cell. Dec.-20, (R16), [illegible]

OR

Explain the principle of solar photovoltaic power generation. May-17, (ME), (R13), [illegible]

OR

Describe the principle of solar photovoltaic energy conversion.

Answer : April-14, (R09), [illegible]

Consider an intrinsic semi-conductor such as silicon, in which all four valence electrons of the atoms participate in chemical bond. Thus, at zero absolute temperature, there are no free electrons present in silicon. When a piece of this material is doped by five valence electron materials such as [illegible] and phosphorus on one side, it leads to an excess electron on that side and the material becomes an n-type semiconductor. [illegible] excess electrons can move freely in the semiconductor lattice.

When this same material is doped with a three valence electron material on the other side, it leads to deficiency of electrons on that side. Thus, the material becomes a p-type semiconductor, and the excess of holes are free to move in the lattice. This piece of material whose one side is p-type and the other side is n-type is called a p-n junction.

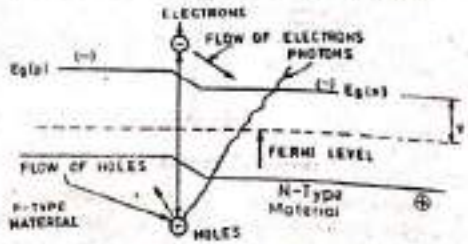


Figure (1)

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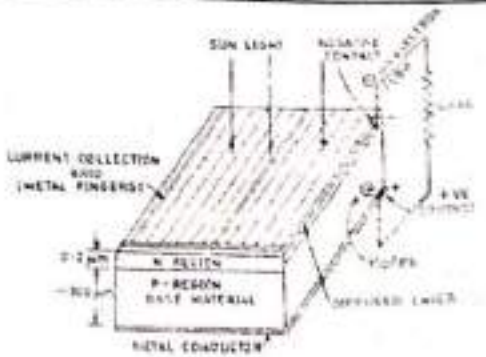

Figure (2)

When this piece of semiconductor material is exposed to sunlight, the p-n junction absorbs some photons. As a result the free electrons from the n-side will tend to flow to the p-side, and the holes from the p-side will tend to flow to the n-side to compensate these deficiencies on both sides. Due to this diffusion of electrons and holes, an electric field (E_i) will be produced from the n-region to the p-region as shown in figure (1). This electric field will increase until it reaches an equilibrium with the sum of the diffusion potentials for holes and electrons.

If the two semiconductor materials are connected with electrical contacts, and are also connected through an external conductor, the free electrons from the n-type material will flow through the conductor to the p-type material. Here, the free electrons will combine with the holes and become electrons. Thus, both the electrons and holes will be removed. The flow of electrons through the external conductor produces an electrical energy, and this will continue as long as more free electrons and holes are being formed by the solar radiation. This is the principles of conversion of solar energy into electrical energy (i.e., photovoltaic conversion). Thus, the combination of both n-type and p-type semiconductors constitutes a photovoltaic (PV) cell or solar cell. These cells produce direct current which can be converted into a.c current. The schematic diagram of the typical solar cell is shown in figure (2).

Q65. Explain the component parts of a solar PV system along with their functions. July-21 (EEE), (R19), [illegible]

Answer :

The solar PV system consists of following components.

1. PV module
2. Balance of system (BOS)

1. PV Module

The PV module in PV system generates the d.c. power. The inverters are used to convert this d.c. power into 220V, 50 Hz a.c. power to run the electrical appliances used in households.

2. Balance of System (BOS)

The components of PV system other than PV module are collectively known as 'Balance of systems'. It includes the storage batteries, an electronic charge controller and an inverter.

Storage Batteries

The storage batteries with charge regulators are used in PV systems for back-up power supply during nights and cloudy days. Usually, batteries are charged during the day time and supply power to the loads.

Electronic Charge Regulator

The storage batteries are equipped with microprocessor based charge regulators, which monitor the voltage and temperature in order to regulate the input and the output currents to prevent overcharging and excessive discharge.

Inverter

The inverter is used for converting the d.c. power from battery or PV array to a.c. power. It is provided with automatic switch-off feature to prevent overloading and short circuit problems.

The block diagram of solar PV system is shown in below figure

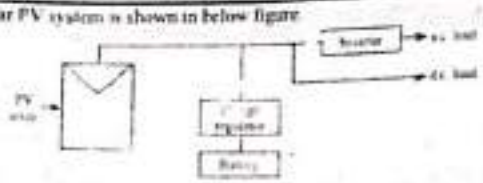

Figure: Block Diagram of Solar PV System

Q66. Explain the classification of solar PV systems.

Answer :

The classification of solar PV systems is explained as follows,

1. **Central Power Station System:** The concept involved in this system is similar to that of conventional type power stations where power is fed to the grid. These power stations are specifically setup to meet the demand of daytime peak loads. The capacity of these plants is upto 6 MW (Peak MW). These type of power stations were installed in USA and Europe.
2. **Distributed System:** The use of distributed form of energy is effective, when solar energy or other renewable energy sources are used.

(i) **Stand-alone PV System:** It comprises of a MPPT controller, which helps in sensing the output (current or voltage) of PV cell array. Also, it is possible to obtain maximum power under any given conditions, by controlling the operating point, through this controller. Then, the output power is fed to the load centres, in the form of ac. When the output obtained exceeds the requirement, it is used for charging the batteries or supplied to the dump heaters.

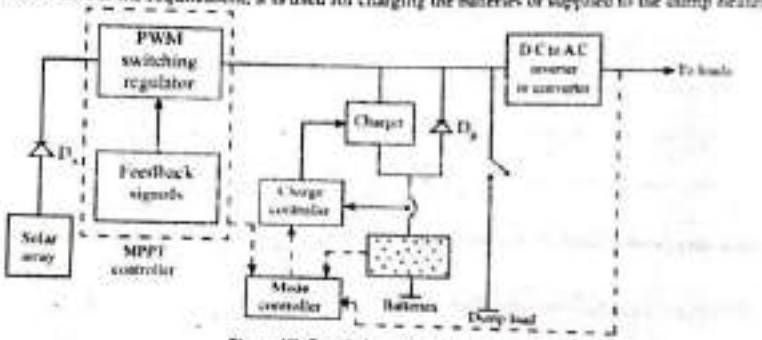

Figure (1): Stand alone Solar PV System

The battery supplies the load when there is no sufficient availability of sun rays. The discharge diode 'D_c' is used to prevent the problem of overcharging of batteries. The array diode 'D_a' isolates the PV cell array from battery, in order to prevent discharge of battery through array during night. A mode controller controls the working of system within specified parameters.

(ii) **Grid-Interactive Solar PV System:** In this system, dump heaters are replaced with grids and excess output power is fed to these grids. The use of battery is eliminated and the continuous supply of power in absence of sunshine is maintained by means of grids. The synchronized operation is achieved by suitable mechanism and D.C power is converted into A.C, by means of an inverter. Then, harmonics are filtered, voltage is adjusted and filtered output power is supplied to the grid.

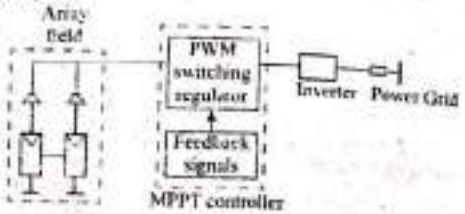

Figure (2): Grid-interactive Solar PV System

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Also, PV modules are being provided with an integral inverter, hence, they are called as A.C PV modules. Thus, the design of PV system is greatly and effectively simplified.

(iii) **Hybrid Solar PV System:** These type of systems are adopted to provide energy from other sources, apart from the PV system. When it is economical to fulfill a part of energy requirement of the system, by other sources like diesel or gasoline generator or non-conventional sources like wind energy or fuel cell, these systems are employed.

Q67. What are the advantages and disadvantages of photovoltaic solar energy conversion?

Answer :

Advantages of Photovoltaic Solar Energy Conversion

1. No moving parts and low maintenance cost.
2. Direct conversion of light to electricity at room temperature.
3. No environmental pollution.
4. Very long life and easy to fabricate.
5. Solar energy is free and no fuel required.
6. Can be started easily as no starting time is involved.
7. These have high power-to-weight ratio, therefore very useful for space application.
8. These can be used with or without sun tracking.

Disadvantages of Photovoltaic Solar Energy Conversion

1. Photovoltaic energy conversion is expensive.
2. Due to the non-availability of solar radiation at nights, the energy received during day has to be stored is suitable storage devices. Reliable batteries for energy storage are not available.
3. For setting up a solar power plant a very large land has to be acquired.
4. Cost of electrical power generated is relatively high.
5. Fabrication of silicon crystals consume more work force and energy.
6. The initial capital required for setting up a solar plant is very high.

Q68. State applications of solar PV System.

Answer :

The first application of solar photovoltaic system was in 1958 to power the space satellite, Vanguard-1. Since then solar cells are chosen as power source in space applications due to their low weight, reliability and durability. Solar cells have survived the harsh physical conditions of space-high vacuum, high radiation and large temperature variations. Success of solar cells in space led to their terrestrial applications. There are three broad categories for PV applications i.e., industrial, social and consumer applications.

1. **Industrial Applications**

(i) **Telecommunications:** PV systems are both economical and reliable power source for telecommunication and several such systems are installed throughout the world.

(ii) **Cathodic Protection:** In this technique, small PV panels may be used to provide, a small direct current very efficiently and this current is impressed on the structure at regular intervals to prevent electrochemical corrosion.

(iii) **Navigational Purpose:** Marine beacons and navigational lights on buoys around the world are now-a-days being powered reliably and cost effectively by simple PV generators, which were earlier powered by kerosene or batteries with several maintenance problems.

(iv) **Remote Aircraft Beacons:** Remote radio and light beacons near the airports may be powered economically by solar PV.

(v) **Alarm Systems:** PV systems are being used to power railway signals, alarm systems, fog, fire and flood hazard warnings, traffic lights and highway telephones.

(vi) **Defence Equipment:** Many defence equipment like mobile telephones, remote instrumentation, remote radar, water purifier, etc., may be efficiently powered by PV.

(vii) **Emergency Equipment:** Battery charging on life boats and rafts and for providing essential service after earthquakes, floods and other natural disasters may be done efficiently by PV system.

2. **Social Applications:** These include providing electric power to remote villages and islands specially in developing countries by PV system where large number of villages remain unconnected to main grid. PV is best suited for rural applications and is environmental friendly.

3. **Consumer Applications:** A very large number of consumer items are now being powered by solar PV. Some of these solar powered products are pocket calculators, watches, clocks, torches, lantern, garden lights, radios, electric fences, toys, etc.

2.3 Wind Energy

2.3.1 Wind Energy

Q69. Give the classification of wind.

OR

What are the sources of wind? Explain.

Answer :

Wind is classified into two types,

1. Planetary or global winds
2. Local winds.

1. Planetary or Global Winds

Planetary winds are those winds which usually blow under the influence of permanent or planetary belts (i.e., high pressure to lower pressure belts). Planetary winds are categorized into three types. They are,

(i) Trade winds

(ii) Westerlies

(iii) Polar winds.

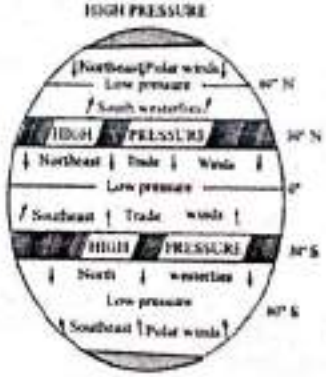

Figure: Planetary Winds

(i) Trade Winds

The word trade is derived from trado (Latin word) which means constant direction. The Northeast trade winds are the winds which blow from northeast to southwest in northern hemisphere. The southeast trade winds are the winds which blow from southeast to northwest in southern hemisphere. Trade winds blow with high speed.

(ii) Westerlies

The South-westerlies winds blow from southwest to northeast in northern hemisphere. The North-westerlies winds blow from northwest to southeast in southern hemisphere. The north-westerlies between 40°s and 60°s latitudes blow with great force because of the absence of land barriers.

(iii) Polar Winds

The Northeast polar winds blow from northeast to southwest in northern hemisphere. The Southeast polar winds blow from southeast to northwest.

2. Local Winds

Local winds are the winds which blow in accordance to local pressure gradient conditions. These are originated from local weather conditions and blow for shorter period of time.

The best example for local winds are the land and sea breezes. Land and sea breezes are produced due to the heating of land and sea. These are characterized by the daily changes in the pressure gradient called diurnal winds. Some of the local winds are characterized due to the change in temperature also.

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Q70. Explain about primary, secondary and tertiary winds and how to make use of them for power generation.

(July-21, (EEE), (R16), Q5(b)) | Model Paper, Q5(b))

Answer :

Primary Winds

The primary winds are also known as planetary winds.

For answer refer Unit-II, Q69, Topic : Planetary or Global Winds.

Secondary Winds

The secondary winds are also known as 'seasonal winds' or 'periodic waves'. These winds change their direction periodically with different seasons. The monsoon winds in India are the example of secondary winds.

Tertiary Winds

The tertiary winds are also known as 'local winds'.

For answer refer Unit-II, Q69, Topic : Tertiary Winds.

Generation of Energy from the Wind

For answer refer Unit-II, Q78.

Q71. Distinguish between local winds and planetary winds.

Answer :

Differences between Local Winds and Planetary Winds

	Local Winds		Planetary Winds
1.	The wind circulation within a smaller area are called as local winds.	1.	The wind circulation on global basis are called as planetary or global winds.
2.	These winds are caused by (i) Differential heating of land surface and water bodies due to solar radiation. (ii) Differential heating of slopes on hillside and of low lands.	2.	The speed and direction of these winds are determined by (i) Differential heating of the earth at equatorial and polar regions. (ii) Rotation of earth about its axis (coriolis force).
3.	Land, mountain and sea breezes are the examples of local winds.	3.	Trade winds, westerlies and polar winds are the three types of planetary winds.
4.	These are characterized by either pressure gradient or by temperature differences.	4.	These are characterised by differences in pressure.
5.	These winds blow over a shorter distances.	5.	These winds blow over longer distances than local winds.
6.	These winds blow near to the earth's surface.	6.	These winds blow away from the earth's surface.
7.	These are unpredictable as they change with the weather.	7.	They can be predictable as they do not change with weather.

Q72. Explain how to locate the potential sites for establishing a wind farm. July-21, (ME), (R16), Q4(b)

OR

Briefly discuss the criteria involved in the selection of site for wind turbine installation.

Sept.-20, (R16), Q6(a)

OR

What are the main considerations in selecting a site for wind generator?

Answer :

Selection of site for wind generators is a most important aspect, when considered with respect to the generation of power and feeding of power into a conventional electric grid. The wind power increases with the speed so these machines should be located in areas, where winds are strong and persistent.

Some of the main considerations in selecting a site for wind generators are discussed below,

1. **High Annual Average Speed**

The power in the wind mainly depends on the velocity of the wind and is given by,

$$P_w = kV^3$$

Where,

P_w – Power in the wind

V – Wind velocity

k – Constant.

2. **Availability of Anemometry Data**

The another factor is to measure the speed of wind without any errors, in order to ensure efficient operation. The anemometry data over a certain time period at the precise spot, where WECS is to be built, is necessary.

3. **Availability of Wind at the Proposed Site**

Maximum energy in the wind is known with the help of V_{50} curve, which predicts the electrical output and hence, revenue return of the WECS machine.

4. **Wind Structure at the Proposed Site**

It is necessary to know the structure of the wind and is defined by V_{50} curve.

5. **Altitude of the Proposed Site**

The winds velocity changes according to the altitudes i.e., the winds have higher velocities at higher altitudes, which in turn produces more power.

6. **Terrain and its Aerodynamic**

It is important to know about terrain of the site to be chosen, as it is preferable that, the wind must flow in horizontal direction.

7. **Local Ecology**

Local ecology should also be considered while choosing the site. If the surface of the ground is bare rock, then the lower hub height is sufficient, but if it contains grass, the hub height should be high, as the grass destructure the wind.

8. **Distance to Roads or Railways**

Transportation of machinery to the site should also be considered.

9. **Nearness of Site to Local Centre or Users**

Distance between the users and the site, where electricity is generated, should also considered. If the distance between them is short, then transmission length, losses and costs are minimized.

10. **Nature of Ground**

The wind machines are erected from ground. So WECS are secured, if ground surface is rigid or stable.

11. **Favourable Land Cost**

Land cost should be low, as it contributes to the WECS cost.

12. **Other Conditions**

Other conditions such as icing, blowing dust, should not be present at the site, which may affect performance of aeroturbine blades.

Q73. Write short notes on applications of wind energy. May-18, (R09), (R13)

OR

Discuss the applications of wind turbines.

Answer :

Applications of Wind Energy

The energy extracted from the wind is mechanical energy and this can be directly used for some applications or can be converted to electricity, heat or fuel. Applications of power turbines up to about 50 kW are for operating irrigation pumps, navigational signals and remote communication, relay stations, weather stations and for offshore oil drilling platforms.

(i) **Pumping Applications**

The typical application is pumping of irrigation water and the other applications include the pumping of water for aqueducts or for pumped-hydro storage of energy.

(ii) **Direct Heat Applications**

Mechanical motion derived from wind power can be used to drive heat pumps or to produce heat from the friction of solid materials or by the churning of water or other fluids and in other cases, by the use of centrifugal and other types of pumps in combination with restriction orifices, that produce heat from friction and turbulence when the working fluid flows through them.

(iii) **Electric Generation Applications**

Wind turbines are used in centralized power transmission to drive A.C. type synchronous generators. In such applications wind electricity from generator is directly supplied to main power lines by using voltage step-up transformers.

(iv) **Sea Transport Applications**

In ferries which travels for short distances, wind turbines are positioned onboard to serve as propeller. Wind turbines are also used to drive large sized cargo ships.

Q74. Describe wind energy potential and its measurement.

Answer :

Observations of speed, temperature and pressure of wind are carried out at National Weather Stations (NWS). Thus, comprehensive data regarding long term information of wind speed, temperature and pressure is provided by NWS. In previous years, data on wind speed is prepared manually

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observer used to predict the speed of wind every hour for one to two minutes and noted it on a strip chart. In recent year observation systems in NWS are provided with automated surface. Samples of speed and direction of wind are done at frequency of 1 Hz, averages for time period over 5 seconds, then rounded. By considering 24 such 5 sec samples, calculation for 2 minutes running average is made. Obtained data is summarised as monthly data sheets and, they are kept available for purchase.

Wind energy potential is the power available in the wind per unit area, therefore it is also known as wind power density. By using data sheets (wind speed data), it is possible to calculate, power available per unit area for year, months or seasons. If wind speed data is available for more than a year, then month data or year data are averaged so as to calculate annual values by month or year.

Wind energy potential, $\frac{P}{A} = \frac{\sum_{i=1}^{n} \frac{P_i}{A}}{n}$

But,

$$P = K.E$$

$$= \frac{1}{2} mV^2$$

$$= \frac{1}{2} (\rho AV)V^2$$

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

Then,

$$\frac{P}{A} = \frac{\sum_{i=1}^{n} \left[\frac{1}{2} \rho_i A V_i^3\right] \frac{1}{A}}{n}$$

$$\frac{P}{A} = \frac{\sum_{i=1}^{n} \frac{1}{2} \rho_i V_i^3}{n}$$

Where,

ρ_i - Wind density of ith observation

V_i - Wind velocity of ith observation

n – Number of observations.

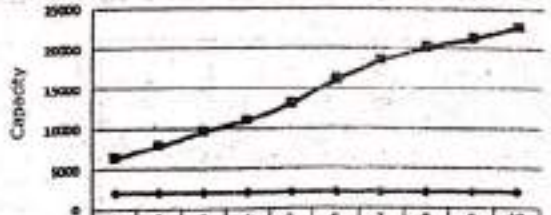
Q75. Discuss the prospects and status of wind energy in India.

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

Prospects of Wind Energy in India

The Ministry of New and Renewable Energy (MNRE) has set a goal in 2015, i.e., the capacity of generating wind power must reach 60,000 MW by the end of the year 2022. By January 2014, in India, the capacity of wind energy for installed units is 20.23 GW among the total electricity generated of 214.6 GW. The wind energy constitutes for about 8.7% of all the renewable energy sources combinedly accounts for 12.6%. More additional capacity includes Maharashtra with 847 MW in the financial year 2013-14. According to the report of India 2010, the employees working directly or indirectly for wind energy industries are 42,000 people. By the year 2020, it reaches to about 60,000 jobs as per the estimation of growth by MNRE. The jobs may be categorized to construction, development, commissioning and project planning.

The wind power generating capacity from 2006 to 2015 in India is shown in the figure below,



	1	2	3	4	5	6	7	8	9	10
YEAR	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CAPACITY(megawatt)	6270	7850	9587	10925	13064	14084	15421	17349	21264	23444

Figure: Wind Power Installed Generating Capacity from 2006 to 2015

atus of Wind Energy In India

India was the fifth largest market in the world by 2013. In India, the gross wind power potential as of about 48,561 MW as per estimation. Major wind energy stations located in India at Tamil Nadu, Maharashtra and Gujarat. The various wind energy capacity (state wise) in India (as of 31 March, 2015) are tabulated below. Of which, Tamil Nadu stands first.

Sl.No.	State	Wind Energy Capacity (MW)
1.	Tamil Nadu	7455.2
2.	Maharashtra	4450.6
3.	Gujarat	3645.4
4.	Rajasthan	3307.2
5.	Karnataka	2638.4
6.	Andhra pradesh	1031.4
7.	Madhya pradesh	879.7
8.	Kerala	35.1
9.	Others	4.30
	Total	23447.3

Q76. Compile and elaborate the meteorological data of wind speeds in India and classify the sites into fair good and excellent wind energy potential sites.

Answer :

Each country will adopt certain services to record and display weather related data which includes wind speed and wind direction.

Wind speed measurements are carried out by using anemometers. The rotating cup anemometer is widely used anemometer for wind speed measurement. Wind direction measurements are done with the help of a wind vane with a direction indicator. Generally, the wind speed data is measured. The anemometer for measuring wind speed works on any one of the mentioned principles below,

1. A simple anemometer is used in which a plate is pivoted to a movable joint along its top edge vertically. The deflection angle of the plate gives the measure of the wind speed with respect to the vertical.
2. The speed of the wind can also be measured by the wind pressure exerts on the flat plate.
3. The rotating cup anemometer contains 3 or 4 cups which are placed uniformly about a vertical axis. The speed of the rotating cups indicates the wind speed.
4. An anemometer based on the effect of sound can also be used for measuring wind speed. The speed of the wind is inversely proportional to the sound travels in the wind. Sound travels in stationary wind at a defined speed. The speed either increases or decreases accordingly if there is a movement of air.
5. The hot-wire anemometer calibrates the speed by sensing the cooling effect of the wind on the hot-wire. The current passed in the anemometer through hot-wire and thus heat is produced.
6. The different types of anemometers for the measurement of wind speed are ultrasonic anemometer laser anemometer and SODAR Doppler anemometer.

A graph is plotted to show the variation effect between the wind speed and the time as shown in figure below.

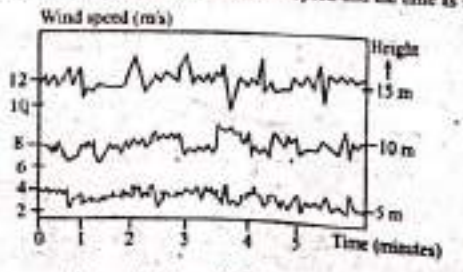


Figure: Variation of Wind Speed and Time

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From the graph, the following points are concluded as,

1. There is an increase in the speed of the wind as the height increases.
2. There is a fluctuations in the wind speed with respect to time. This means, there is a presence of unsteady air movements at the recorded area.
3. At a wider range of frequencies the turbulences are extended.

Classification of Wind Energy Potential Sites

The classification of wind energy potential resources are as follows,

Wind Energy Potential Sites	Density of Wind Power (W/m²)	Wind Speed (m/s)
Fair	100 – 150	4.3 – 5.0
Good	150 – 200	5.0 – 5.5
	200 – 300	5.5 – 6.3
Excellent	300 – 400	6.3 – 7.0
	400 – 600	7.0 – 8.2
	600 – 1000	8.2 – 10.1

Q77. Discuss the energy potential from wind in the context of India. Where can wind turbines be installed?

Answer : May-19, (R15), Q6(a)

Energy Potential From Wind in the Context of India

For answer refer Unit-II, Q75.

Suitable Places for Installation of Wind Turbines

For answer refer Unit-II, Q24.

2.3.2 Horizontal And Vertical Axis Wind Mills

Q78. Explain with a neat sketch the construction and working of wind electric generating plant

May-19, (R09), Q4(b)

OR

Describe with a neat sketch the working of a wind energy conversion system.

OR

Describe with a neat sketch the working of wind energy conversion system with main components.

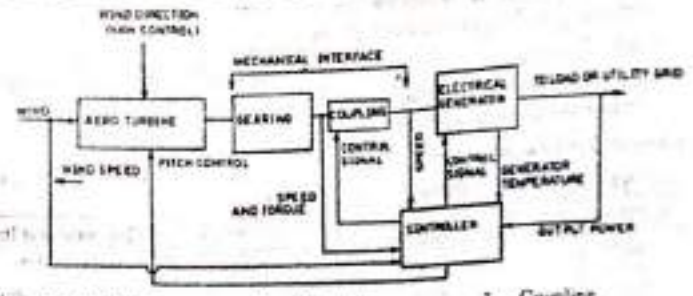
Answer : July-21 (ME), (R16), Q4(a)

Wind Energy Conversion System

The main components of a wind energy system are,

1. Aeroturbine
2. Gearing
3. Coupling
4. Electrical generator
5. Controller.

The main function of aeroturbine is to convert energy in moving air to rotary mechanical energy. In the case of horizontal wind axis turbine, they may require pitch control and yaw control. The rotary mechanical energy generated by the aeroturbine is transmitted to an electrical generator with the help of gears and coupling. The output of this generator is connected to the load or power grid as per the requirements. The locations where the wind is in one direction of the turbine, is designed in such a way that the orientation of the rotor is fixed so that the swept area is perpendicular to the predominant wind direction. Such a machine is said to be yaw fixed. The function of controller is to sense the wind speed, wind direction, shaft speeds and torques at one or more points. It detects the output power and temperature of generator. It also senses the proper control signals which helps in equating the electrical output and wind energy input. Due to the occurrence of strong winds, electrical faults etc., the wind energy system can be protected by the controller.



1. Aeroturbine 2. Gearing 3. Coupling
4. Mechanical interface 5. Electrical Generator 6. Controller

Figure: Basic Components of a Wind Energy System

Q79. Give an overview of control techniques for wind turbine systems along with their significance.

Answer : July-21 (EEE), (R16), Q6a

The various control for wind turbine systems are as follows.

1. Generator control
2. Transmission control
3. Load control

1. Generator Control

Generator control schemes are decided by the generator being used. Generators that are most commonly used for production of electrical power from wind power are, Permanent magnet generator, D.C generator and induction generator.

2. Transmission Control

Wind energy generator is connected to load by means of transmission link. Silicon controlled type rectifier is used to vary power supplied to load through transmission link. Such equipment consists of thyristors (power electronic devices). The gate of an individual thyrister is supplied with delayed trigger pulses control in conduction span that is on time and off time of thyristors is obtained.

3. Load Control

For wind turbine, stepwise load approximation to speed or power characteristic is obtained by employing load resistance. For a specific speed of wind, discrete resistance is selected so that turbine operates closely at its maximum value of C_p (coefficient of performance) while generator is set to operate within permissible current loading. The method of generator control is of low cost and simple, and preferred for small wind turbines of stand alone type.

Q80. Distinguish between onshore and offshore wind energy systems.

Answer : July-21, (EEE), (R16), Q6a

	Onshore Wind Energy System		Offshore Wind Energy System
1.	These are large installations of wind turbines located on land.	1.	These are installations located in water bodies.
2.	The wind speeds on onshore is less than the offshore and not steadier.	2.	These systems have the potential to generate more electricity at a constant rate due to higher and more consistent wind speeds.
3.	The onshore farms create noise pollution and effect humans and environment negatively and also change the patterns of the surface air.	3.	Generally, offshore wind farms are far away from the human residences and have minimum impact on environment.
4.	These are easily accessible.	4.	Difficult to access these systems.
5.	Cheaper to build and maintain.	5.	Expensive to build and difficult to maintain.

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Q81. How are WEC systems are classified? Discuss in detail. April-18, (EEE), (R13), Q6(b)

OR

Give a brief description on types of wind turbines.

[April-18, (ME), (R13), Q7(a)] [June-18, (R13), Q7(a)]

OR

Explain various configuration of wind turbines in detail with neat diagram.

Answer : May-13, (R09), Q4(a)

Wind Mill

It is a device which converts the kinetic energy of the wind into the mechanical energy of the turbine shaft. It is also called wind turbine.

Classifications of Wind Mills

There are two broad classifications of wind mills,

(i) Horizontal Axis Machines

The axis of rotation of wind mill is horizontal and the aeroturbine plane is vertical facing the wind.

(ii) Vertical Axis Machines

The axis of rotation is vertical. The sails or blades may also be vertical, as on the ancient persian wind mills or so, as on the modern Darrias rotor machine.

Wind mills can also be classified based on the following parameters.

1. Electrical Power Output

(i) Small Scale (upto 2 kW)

These might be used on farms, remote applications and other places requiring relatively low power.

(ii) Medium Size Machines (2-100 kW)

These wind turbines may be used to supply less than 100 kW rated capacity, to several residences or local use.

(iii) Large Scale or Large Size Machines (100 kW or up)

These are used to generate power for distribution in central power grids.

2. Type of Output Power

(i) D.C output

(ii) A.C output

3. Rotational Speed of Wind Mill

(i) Constant speed

(ii) Nearly constant speed

(iii) Variable speed with fixed pitch blades.

4. Utilization of Output Mode

(i) Battery storage

(ii) Direct connection to an electromagnetic energy converter

(iii) Other forms of storage

(iv) Interconnection with conventional electric utility grids.

Q82. Explain the advantages and limitations of wind energy conversion systems.

Answer : May-17, (ME), (R13), Q6(a)

Advantages of Wind Energy Conversion System

1. There is no requirement of fuel supply.
2. Wind power plant consumes less time for its construction.
3. It is a non-polluting power system, thereby no adverse effect is produced on the environment.
4. Wind turbine occupies very small floor area.

Disadvantages of Wind Energy Conversion System

1. This system is noisy in operation.
2. Only limited amount of power is produced, i.e., ranging from 30 kW to 300 kW.
3. It involves very high initial cost.
4. The overall weight of the wind power system is relatively high.

Q83. What are the various components of a horizontal axis wind turbine explain?

Answer : May-19, (R18), Q7(b)

The main components of horizontal axis wind turbine are,

1. Turbine blades
2. Generators
3. Yaw system
4. Hub
5. Nacelle
6. Towers.

1. Turbine Blades

Epoxy composites and glass fibre are used in the manufacture of turbine blades. To reduce the air friction, the blades are slightly twisted from outer tip. Modern turbines have two or three blades having aerofoil type cross section.

2. Generator

The type of generators used are either constant speed or variable speed generators. Variable speed generators are expensive and inaccurate and are not used in common practice. There are different types of constant speed generators, among which synchronous induction and permanent magnet types are used.

3. **Yaw System**

Yaw system controls the position of the nacelle around the vertical axis. Hence, by using yaw system, the position of nacelle is adjusted such that it faces the wind. The yaw system is provided at the base of the nacelle.

4. **Hub**

The central part of a rotor, where all the blades are connected is called hub. The mechanism for pitch angle control is provided in the hub.

5. **Nacelle**

It houses the rotor brakes, gearbox, generator, electrical switch gear and control. The switch gear and control block enables to control the system, according to the requirement. It is placed on the top of a tower.

6. **Towers**

Four types of towers generally used are as follows,

(i) Truss tower

(ii) Pole tower

(iii) Reinforced concrete tower

(iv) Built up shell-tube tower.

The most common and preferred tower is truss tower, because it is widely applicable. The parts of truss tower are stiff, inexpensive, readily available and can be transported easily. Truss tower is designed to withstand the wind load, even if they occur frequently over a short period.

Q84. Describe horizontal axis type aero generators.

Apr-'08, (EEE), (R13), Q6(a)

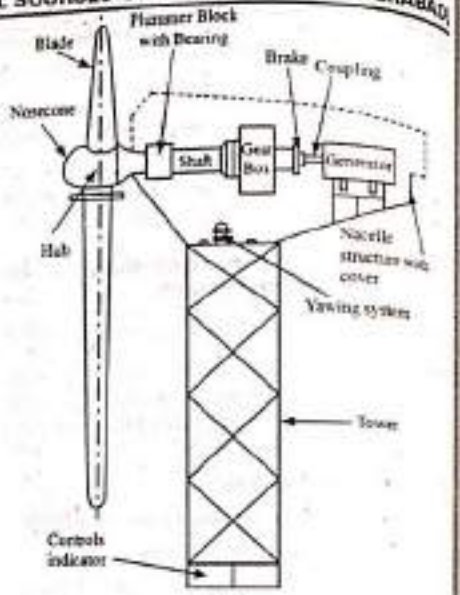
OR

Write the working principle of horizontal axis turbine.

Answer :

In a horizontal axis wind turbine the axis of the rotor's rotation is parallel to the wind stream and the ground. It is built with a propeller type rotor on a horizontal axis i.e., a horizontal main shaft. It may be two (or) three bladed (or) more blades. The rotor converts linear motion of the wind into rotational energy that is used to drive a generator.

In this type of design, rotor drives a generator through a step up gear box. The blade rotor is usually designed to be oriented downwind of the tower. The components are mounted on a bed plate which is attached on a pintle at the top of the tower. The rotor blades are continuously bent by unsteady aerodynamic, gravitational and inertia loads, when the machine is in operation. If the blades are made of metal, flexing reduces their fatigue life with rotor, the tower is also subjected to above loads, which may cause serious damage. If the vibrational modes of the rotor happen to coincide with one of the natural mode of the vibration of the tower, the system may shake itself to pieces. Because of the high cost of the blade rotors with more than two blades are not recommended. Rotors with more than two, say 3 or 4 blades would have slightly higher power coefficient.



Figure

Working: The basic principle is that the flow of air is parallel to the rotational axis of the turbine blades. The wind passes on both surfaces of the blade creating a lower pressure area above the air foil. The pressure differential between top and bottom surface results in aerodynamic lift. The blades of the turbine are constrained to move in a plane with the hub as its centre, the lift force causes rotation about the hub. In addition to lift force, a drag force perpendicular to lift force impedes rotor rotation. It has high lift-to-drag ratio.

Q85. Explain various horizontal axis wind turbines.

Answer :

Horizontal Axis Wind Mills

The important horizontal axis wind turbines are as follows,

1. **Horizontal axis using two aerodynamic blades**

In this design, the parts of the windmill are placed on the bed plate which is fastened to a pintle on the top of the tower. A step up gearbox is used to drive the generator. The aerodynamic blades are generally positioned downwind of the tower. During the working of the windmill, the rotor blades are always bent due to their aerodynamic structure, inertia and gravitational loads. The bending (flexing) is more if the blades are made of metal. This decreases the fatigue life and causes damage to the windmill. The cost of the blades is so high

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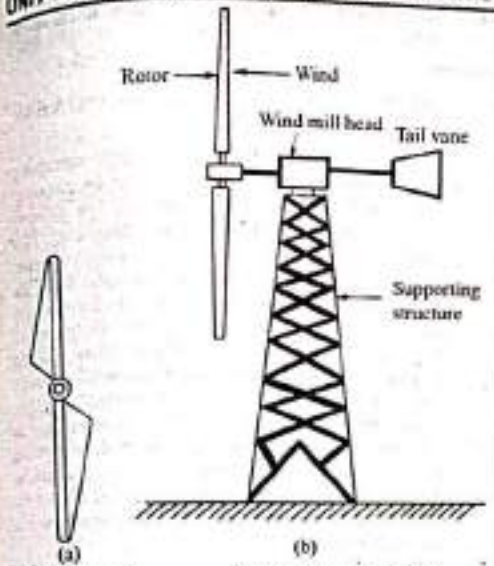

(a) Two blade profile

(b) Schematic of a horizontal axis type wind mills

Figure (1) : Horizontal Axis Two Aerodynamic (Blades Wind)

2. **Horizontal Axis Propeller Type using Single Blades**

It consists of a single blade of long length which is mostly below 60m. This blade is placed on a rigid hub. The tower shadow, gravity and the changes in the wind directions might be factors causing the bending moments if the length of the blade is above 60m. In order to balance the long length blade centrifugally, counter weight is used. Using the counter weight of less cost will decrease the overall cost of the windmill.

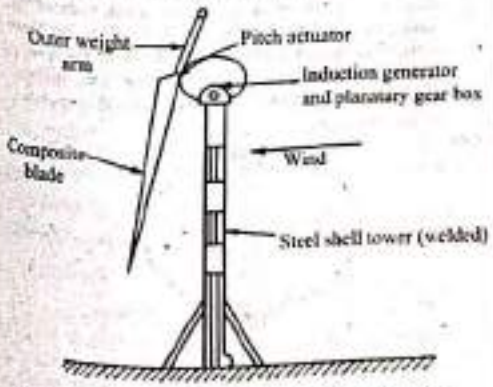

Figure (2): Horizontal Axis Single Blade Wind Mill

3. **Horizontal Axis Multi-Bladed Type**

These windmills have more number of blades which are made of aluminum or sheet metal. The following are the advantages of this wind mill.

(i) High strength to weight rotors

(ii) Simple in design and construction

(iii) Less cost

(iv) High starting torque

(v) Good power coefficient.

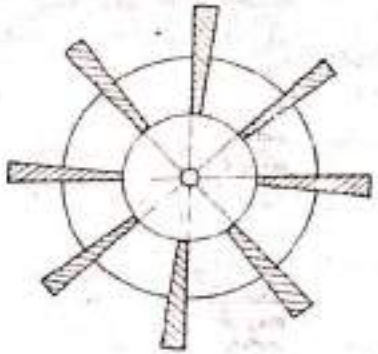

Figure (3): Horizontal Axis Multibladed Type

4. **Horizontal Axis Dutch-Type Wind Mill**

In this windmill, the blades were made of wooden slats. These are the oldest models of windmills and were used for a long time mostly in Europe. Generally, the windmill consists of 4 blades.

Figure (4): Horizontal Axis Dutch-Type Wind Mill

5. **Sail-Type**

This windmill was invented recently. Cloth, plastic and nylon are the materials used for the blade surfaces of the windmill. The arrangement of the blades resembles mast and pole or the sail wings.

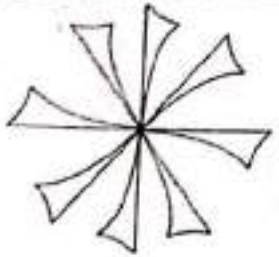

Figure (5): Blades of Sail-Type Wind Mill

Q86. Write the operating principle of vertical axis wind turbine.

Answer :

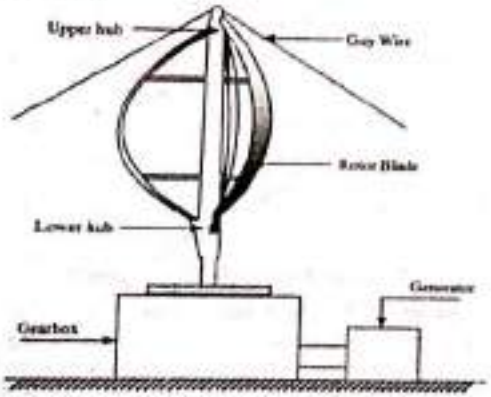

Figure: Vertical Axis Windmill

In a vertical axis wind mill, the rotor's rotation is perpendicular to the wind stream. It mainly consists of a tower, rotor, blades, generator, gearbox etc. The rotor most commonly used is Darrius type rotor. The tower is a vertical hollow shaft which rotates freely about vertical axis. The maximum height of the tower is about 100 m. This type of wind mill may have two or three blades. The blades are thin and curved in shape, with an airfoil cross-section. The height of the rotor may be about 94 m with a diameter of 65 m. The gearbox, generator etc., are mounted at the bottom of the tower at ground. This facilitates the elimination of nacelle which reduces the weight on the tower.

Working: A vertical axis wind mill does not require a yaw control as it accepts wind from all the directions. The wind passing through the blades rotates the blades,. This rotation of the blades causes the rotor rotation which is mounted on a rotating tower. The tower rotation runs the generator which is in connection with it. Thus power is generated by the generator. The major advantage of vertical axis windmill is, it is independent of wind direction. When the direction of wind changes, it do not turn into the stream. These machines are called panemones.

Q87. Enumerate the types of vertical axis wind turbines.

Answer :

The two main vertical axis wind turbines are as follows.

1. **Savonius Rotor Windmill**

Savonius rotor is used for wind-energy conversion systems and is of simplest type like a cup anemometer. This is self-starting, requires relatively low velocity winds for operation, thus have low efficiency. This system of conversion has a vertical axis which eliminates the expensive power transmission system from the rotor to the axis, and it is not sensitive to the direction of wind. Savonius rotor produces power effectively for the wind as slow as 10 km/hr, whereas most propeller type wind machines require about 15 km/hr for efficient operation. Savonius rotor consists of two half-cylinders facing opposite directions in such a way as to have an S-shaped cross-section. Two edges of S-shape overlap to leave a wide space between the two inner edges, so that each of these edges is near the central axis of the opposite half cylinder. Due to its simple structure it is easy to manufacture.

Figure (1) : Savonius Rotor

2. **Darrius Rotor Wind Mills**

This rotor has been invented by a french engineer G.J.M Darrius in 1925. In this arrangements, the blades are supported in a way that minimizes the bending stresses in the normal operations. It consists of two or three thin curved blades. The cross-section of the blades is airfoil shape with constant chord length. Both ends of the blades are attached to a vertical shaft. Thus, the force in the blade due to rotation is pure tension. These wind mills can withstand the wind forces due to the stiffness provided by the pure tension. The blades thus made are lighter in weight.

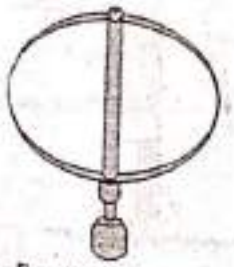

Figure (2) : Darrius Rotor

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Q88. With a neat sketch explain the types of wind turbines.

Answer : July-21 (ME), (R16), Q5(a)

The wind turbines are mainly classified into two categories. They are,

1. **Horizontal Axis Wind Turbines**

For answer refer Unit-II, Q55.

2. **Vertical Axis Wind Turbines**

For answer refer Unit-II, Q56.

Q89. Describe the salient features of a vertical-axis wind turbine with the help of a diagram.

Answer : July-19, (R15), Q6(a)

Salient Features of a Vertical Axis Wind Turbine

1. Vertical axis wind turbines consists of less components. Thus, comparatively less parts will undergo breakdown and wearing.
2. Operation of these turbines is independent of wind direction. As axis about which these turbines rotate, lies at almost right angle to the direction of the wind, they are capable of receiving wind from all directions. Therefore, design of yaw devices becomes simple.
3. Components such as gear box and generator are positioned at ground level. Therefore, maintenance becomes easier and complexity of tower design is reduced.
4. Can be employed for synchronous applications without using pitch control devices.
5. It is possible to design vertical axis wind mills of smaller sizes by scaling down to a considerably lower value, so that they fit on rooftops for urban applications.
6. Transportation and installation of these turbines is easy.
7. These turbines possess aerofoil pitch angle, thus drag reduction at low and high pressures is possible.

For figures refer Unit-IV, Q37.

Q90. Discuss the advantages and disadvantages of horizontal and vertical axis wind turbines.

Answer :

Horizontal-axis Wind Mills

Advantages

1. Orientation of blades, helps in maintaining stability.
2. Tall tower allows access to stronger wind, thereby increasing the power generation capacity.
3. Tall tower allows placement on uneven land or in offshore locations.
4. It can be installed in forests, above tree line.
5. These wind mills are self-starting.
6. It is cheaper per unit of output, because of higher production volume and larger size.

Disadvantages

1. It is difficult to operate at low heights and in case of turbulent winds.
2. The tall towers and long blades are difficult to transport on the sea and on land.
3. Supply of these wind mills is less than the demand, as per previous observations.
4. It has more environmental impacts.

Vertical-axis Wind Mills

Advantages

1. Easier to maintain, because most of their moving parts are located near the ground.
2. As the rotor blades are vertical, yaw control is not needed, which reduces the cost.
3. These have a higher aerofoil pitch angle, thus, leading to reduced drag at low and high pressures.
4. It can operate at low heights.
5. There is no need of orientation of wind mill with the direction of the wind.

Disadvantages

1. They possess low efficiency comparatively.
2. Height and sweep area of the wind mill are limited.
3. These wind mills need to be installed on a relatively flat surface of land.

Q91. What are the advantages and disadvantages of horizontal axis windmill over vertical axis windmill.

Answer :

Advantages

1. A horizontal axis windmill or wind turbine (HAWT) has a variable blade pitch which helps the blades in collecting maximum amount of wind energy during the day.
2. The base of the tower in a HAWT is tall. This makes the blades to access stronger wind at sites with wind shear. In VAWT, tower base is short and thus it cannot use wind speed at higher elevations. Thus generates less power.
3. The efficiency in a HAWT is higher when compared to VAWT. This is primarily because the blades in a HAWT always move perpendicular to the wind and thus receives maximum power through the whole rotation.

   In a VAWT, the blades have reciprocating actions which require the airfoil surfaces to backtrack against the wind for part of the cycle. In the process of backtracking against the wind, the efficiency reduces in VAWT.

4. In a HAWT, the wind strikes the face of the blades at a consistent angle regardless of the position of its rotation. This causes the overall wind loading to be consistent over the course of rotation. Due to this consistency in wind loading, the vibrations and hence noise is reduced.

   In a vertical axis windmill, the blades being vertical, the wind does not strike the face of the blade at consistent angle. The inconsistency in wind loading causes stress in each blade and thus changes the sign twice during each revolution. Thus with this the probability of blade failure is increased due to the reversal of the stress.

Disadvantages

1. As the horizontal axis wind turbines consists of tall towers and long blades (upto 45 meters), the transportation of the auxiliary equipment to the site is very difficult. In case of VAWT, the tower is short and hence easy to transport.
2. The cost of installing the towers in a HAWT is very expensive as it requires very tall and cost effective cranes as well as highly skilled personal. On the other hand installation of VAWT is less expensive.
3. To support the heavy blades, gear box and generator in a HAWT, massive tower is to be constructed. In case of VAWT, the generators can be located nearer to the ground and hence requires small tower.
4. The design of HAWT is complex when compared to a VAWT.
5. The HAWT is not omnidirectional like VAWT.
6. HAWT requires additional yaw control mechanism to turn the blades and needle towards the wind. But, a VAWT requires no steering mechanism to head the rotor into the wind.

Q92. Explain the procedure of wind generation and control for electrical energy.

Answer: Dec.-20, (R16), Q5

Wind Generation

For answer refer Unit-II, Q78.

Procedure of Control for Electrical Energy

Out of Syllabus.

Q93. Compare horizontal and vertical axis windmills and briefly list of various types of rotar systems.

Answer: Sept.-20, (R16), Q5(a)

Difference between Horizontal and Vertical Axis Wind Mills

For answer refer Unit-II, Q30.

Types of Rotar Systems

For answer refer Unit-II, Q26.

Q94. Comment on the relative features of HAWT and VAWT. April-14, (R09), Q5(a)

Answer :

Features of HAWT

For answer refer Unit-II, Q90, Topic: Advantages.

Features of VAWT

For answer refer Unit-II, Q89.

Q95. A HAWT having the rotor diameter as 80 m is rotating at 40 rpm. The wind speed is 20 m/s at 1 atm and 27°C. Calculate the torque produced at the shaft for maximum output the of the turbine.

Answer : June-18, (R13), Q1(b)

Given that,

Diameter of rotor, $D = 80$ m

Radius of rotor, $R = \frac{80}{2} = 40$ m

Speed of wind, $u_0 = 20$ m/s

Pressure of wind, $P = 1$ atm $= 1.01325 \times 10^5$ Pa

Temperature of wind, $T = 27°C = 300$ K

Speed of the rotor, $\omega = 40$ rpm

$$= 2\pi \times \frac{40}{60}$$

$$= 4.188 \text{ rad/s}$$

Area of motor, $A = \pi R^2$

$$= \pi \times (40)^2$$

$$= 5026.548 \text{ m}^2$$

Density of air, $\rho = \frac{P}{RT}$

$$= \frac{1.01325 \times 10^5}{287 \times 300} \quad (\because R = 287 \text{ J/kg K})$$

$$= 1.177 \text{ kg/m}^3$$

For maximum output of the turbine,

Interference factor, $a = \frac{1}{3}$

Maximum power coefficient, $C_{P_{max}} = 0.593$

T_{ip} – Speed ratio is given as,

$$\lambda = \frac{R\omega}{u_0}$$

$$= \frac{40 \times 4.188}{20}$$

$$= 8.376$$

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Power available in wind is given as,

$$P_a = \frac{1}{2}(\rho A)u_0^3$$

$$= \frac{1}{2} \times (1.77 \times 5026.548) \times (20)^3$$

$$= 23664987.98 \text{ W}$$

$$= 23.665 \text{ MW}$$

The maximum torque acting on the ideal turbine rotor is given as,

$$T_M = \frac{P_a}{u_0} R$$

$$= \frac{23.665}{20} \times 40$$

$$= 47.33 \text{ N}$$

Maximum torque coefficient is given as,

$$C_{T_{max}} = \frac{C_{P_{max}}}{\lambda}$$

$$= \frac{0.593}{8.376}$$

$$= 0.07079$$

∴ Torque produced at the shaft for maximum output of the turbine is,

$$T_{shaft} = T_M \times C_{T_{max}}$$

$$= 47.33 \times 0.07079$$

$$= 3.348 \simeq 3.35 \text{ N}$$

2.3.3 Performance Characteristics - Betz criteria

Q96. Write a short note on the performance of wind mills.

Answer :

The performance of a wind mill is defined as 'efficient of performance' (C_p)

$$C_p = \frac{\text{Power delivered by the rotor}}{\text{Maximum power available in the wind}}$$

$$C_p = \frac{P}{P_{max}} = \frac{P}{\frac{1}{2}\rho A V^3} \quad ...(1)$$

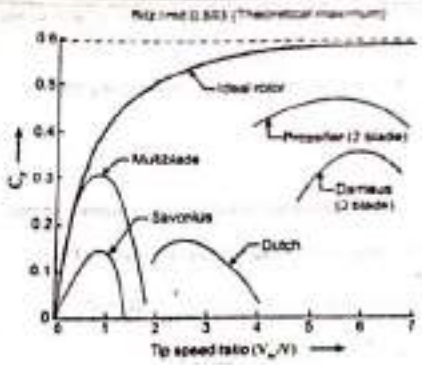
Where,

ρ – Density of air

A – Swept area,

V – Velocity of wind

The plot between C_p and tip speed ratio ($TSR = V_w/V$) is shown in below figure.



Figure

Where, V_w – Speed of blade tip.

C_p is lowest for Savonius and Dutch types, whereas the propeller types have the highest value of C_p.

In the designing of wind mills, it is important to keep the power to weight ratio at the lowest possible level.

Q97. Derive the expression for power developed due to wind energy.

[May-17, (ME), (R13), Q6(b)] [May-17, (EEE) (R13), Q6]

OR

Derive the expression for energy available in the wind.

Answer :

Expression for Energy Available in the Wind (or) Power Available in the Wind

The energy available in the wind can be calculated by applying the concept of kinetics. The principle of wind machines is to convert kinetic energy of wind into mechanical energy.

Let,

V – Velocity of wind in km/h

ρ – Density of air (at sea level, $\rho = 1.225$ kg/m^3)

A – Area through which the air flows.

The quantity of air passing in unit time through the area 'A' with velocity 'V' is gives by,

∴ Mass = Volume of air × Density of air

$$m = (V \times A) \times \rho$$

The kinetic energy of the wind is given by,

$$K.E = \frac{1}{2} m V^2$$

$$K.E = \frac{1}{2} \times (\rho \times A \times V) \times V^2 \text{ watts}$$

$$K.E \text{ or total power, } P_{total} = \frac{1}{2} \times \rho \times A \times V^3 \text{ watts}$$

Therefore, the power output of the wind will varies as cube of the wind velocity (i.e., $P_{wind} \propto V^3$).

The area through which the air flows is given by,

$$A = \frac{\pi}{4} \times D^2 \quad ...(2)$$

Where,

D – Diameter in horizontal axis aeroturbines

By substituting equation (2) in equation (1),

$$K.E \text{ or } P_{Wind} = \frac{1}{2} \times \rho \times \frac{\pi}{4} \times D^2 \times V^3$$

$$P = \frac{1}{8}\rho\pi D^2 V^3$$

∴ The above equation represents the energy available in the wind or power available in the wind.

Q98. What is Betz limit and show that a wind turbine cannot extract more than 59.3% wind energy?

Sept-20, (R16), Q6(b)

OR

Show that a wind turbine cannot extract more than 59.3% of wind energy.

April-18, (ME), (R13), Q6(b)

OR

Derive an expression for maximum power coefficient for a horizontal axis wind turbine.

April-18, (ME), (R13), Q7(b)

OR

Prove that the maximum power coefficient C_p for a windmill is 0.593.

OR

Show that for horizontal wind mill the maximum power can be obtained when exit velocity = (wind velocity)/3 and the maximum power is $\frac{8}{27}\rho AV^3$.

OR

What is the Betz limit and how is it applied to wind turbines.

Answer : **[July-21 (ME), (R16), Q6(b)] [Model Paper, Q6(b)]**

Energy from the wind stream is extracted by a wind turbine, by converting the kinetic energy (K.E.) of the wind into mechanical energy (i.e., rotational motion) required to operate an electric generator.

The following assumptions are made to derive the energy equation.

1. The flow of wind is "incompressible". Thus, the air stream diverges as it passes through the turbines.
2. The mass flow rate of the wind is "constant" at far up stream, at the rotor and at far down stream.

Let,

p – Atmospheric wind pressure

P_{up} – Pressure on upstream of wind turbine

P_{dn} – Pressure on downstream of wind turbine

V – Atmospheric wind velocity

V_{up} – Velocity of wind upstream of wind turbine

V_{di} – Velocity of wind at blades

V_{dn} – Velocity of wind downstream of wind turbine before the wind front reforms and regains the atmosperic level.

A_{di} – Area of blades

$\dot{m}$ – Mass flow rate of wind

ρ – Density of air.

The kinetic energy of wind stream passing through the turbine rotor is given by.

$$K.E = \frac{1}{2}\dot{m}V_{up}^2$$

Mass flow rate of the wind,

$$\dot{m} = \rho A_{di} V_{di}$$

$$K.E = \frac{1}{2}\rho A_{di} V_{di} \times V_{up}^2 = \frac{1}{2}\rho A_{di} V_{di}^3 \quad ...(1)$$

The force on the rotor disc, F is given by,

$$F = (P_{up} - P_{dn})A_{di} \quad ...(2)$$

The force on the rotor disc is also given by,

$$F = \dot{m}[V_{up} - V_{dn}] \quad ...(3)$$

[i.e., Momentum per unit time form upstream to downstream wind]

By applying Bernoulli's equation to upstream and down stream flows,

$$p + \frac{1}{2}\rho V_{up}^2 = P_{up} + \frac{1}{2}V_{di}^2 \quad ...(4)$$

$$\text{and, } P_{dn} + \frac{1}{2}\rho V_{di}^2 = p + \frac{1}{2}\rho V_{dn}^2 \quad ...(5)$$

By solving the equations (4) and (5),

$$P_{up} - P_{dn} = \frac{1}{2}\rho[V_{up}^2 - V_{dn}^2] \quad ...(6)$$

By equating the equations (2) and (3),

$$(P_{up} - P_{dn})A_{di} = \dot{m}[V_{up} - V_{dn}] = \rho A_{di} V_{di}[V_{up} - V_{dn}] \quad ...(7)$$

By solving equations (6) and (7),

$$\frac{1}{2}\rho[V_{up}^2 - V_{dn}^2] = \rho V_{di}[V_{up} - V_{dn}]$$

$$V_{di} = \frac{[V_{up} + V_{dn}]}{2} \quad ...(8)$$

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Then,

In a wind turbine system "speed flow work", W, is equal to the difference in kinetic energy between upstream and downstream of turbine for unit mass flow (m = 1)

Therefore,

$$W = (K.E)_{up} - (K.E)_{dn}$$

$$W = \frac{1}{2}[V_{up}^2 - V_{dn}^2]$$

The power output 'P' of wind turbine (rate of workdone) is given as,

$$P = \frac{1}{2}\dot{m}[V_{up}^2 - V_{dn}^2] = \dot{m}\left[\frac{V_{up}^2 - V_{dn}^2}{2}\right]$$

$$= \rho A_{di}\left[\frac{V_{up} + V_{dn}}{2}\right]\left[\frac{V_{up}^2 - V_{dn}^2}{2}\right]$$

$$\left[\because \dot{m} = \rho A_{di} V_{di} = \rho A_{di}\left[\frac{V_{up} + V_{dn}}{2}\right], \text{ from equation (8)}\right]$$

$$\therefore \quad P = \frac{1}{4}\rho A_{di}[V_{up} + V_{dn}][V_{up}^2 - V_{dn}^2] \quad ...(10)$$

The P_{max} (maximum turbine output) is obtained by differentiating the equation (10) with respect to V_{dn} and equating to zero.

$$\text{i.e., } \frac{dP}{dV_{dn}} = 3V_{dn}^2 + 2V_{up}V_{dn} - V_{up}^2 = 0$$

The above quadratic equation has two solutions. They are,

$$V_{dn} = -\frac{1}{3}V_{up} \text{ and } V_{dn} = V_{up}$$

For power generation, $V_{dn} < V_{up}$.

Therefore,

$$V_{dn} = \frac{1}{3}V_{up} \quad ...(11)$$

By substituting the equation (11) in equation (10),

$$P_{max} = \frac{1}{2}\rho A_{di}\left[V_{up} + \frac{1}{3}V_{up}\right]\left[V_{up}^2 - \left[\frac{1}{3}V_{up}\right]^2\right]$$

$$= \frac{1}{3}\rho A_{di}\left[\frac{4}{3}V_{up}\right]\left[\frac{8}{9}V_{up}^2\right]$$

$$\therefore \quad P_{max} = \frac{8}{27}\rho A_{di} V_{up}^3 \quad ...(12)$$

$$= \frac{16}{27}\left[\frac{1}{2}\rho A_{di} V_{up}^3\right]$$

$$= 0.593\left[\frac{1}{2}\rho A_{di} V_{up}^3\right]$$

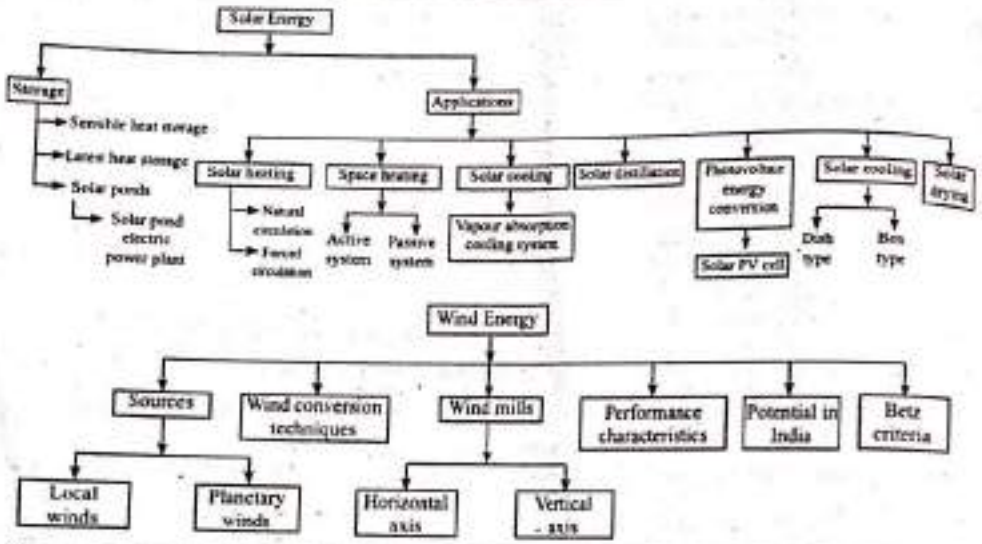
Total power in the wind stream, $P_{wind} = \frac{1}{2}\rho A_{di} V_{up}^3$ ...(13)

$$\therefore \quad P_{max} = 0.593\, P_{wind}$$

Then, the coefficient of power is given by, $C_p = \frac{P_{max}}{P} = 0.593$ ...(14)

The factor 0.593 is known as Betz limit.

MEMORY MAP



FREQUENTLY ASKED QUESTIONS AND IMPORTANT QUESTIONS

Q1. How are WEC systems are classified? Discuss in detail. FREQUENTLY ASKED 4 TIMES

Ans: Refer Q81. [April-18, (EE), (R13), Q6(b) | June-18, (R12), Q7(a) | April-18, (ME), (R13), Q7(a) | May-13, (R09), Q4(a)]

Q2. What is Betz limit and show that a wind turbine cannot extract more than 59.3% wind energy? FREQUENTLY ASKED 3 TIMES

Ans: Refer Q98. [Sept.-20, (R18), Q4(b) | April-18, (ME), (R13), Q6(b) | April-18, (ME), (R13), Q7(b)]

Q3. Explain the mechanism of photoconduction in a PV cell. FREQUENTLY ASKED 3 TIMES

Ans: Refer Q64. [Dec.-20, (R18), Q3 | May-17, (ME), (R13), Q5(b) | April-14, (R09), Q4(a)]

Q4. Describe the working of a concentration gradient solar pond. FREQUENTLY ASKED 2 TIMES

Ans: Refer Q46. [May-19, (R15), Q5(b) | May-15, (R09), Q3(a)]

Q5. Explain the working of solar cooling system with the help of a diagram. FREQUENTLY ASKED 2 TIMES

Ans: Refer Q50. [July-19, (R15), Q5(a) | May-17, (ME) (R13), Q5(a)]

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Q6. Explain the working of solar distillation process with a neat sketch. FREQUENTLY ASKED 2 TIMES

Ans: Refer Q59. [June-18, (R13), Q4(b) | May-13, (R09), Q3(b)]

Q7. Briefly discuss the criteria involved in the selection of site for wind turbine installation. FREQUENTLY ASKED 2 TIMES

Ans: Refer Q72. [Sept.-20, (R18), Q6(a) | July-21 (ME), (R18), Q4(b)]

Q8. Explain with a neat sketch the construction and working of wind electric generating plant FREQUENTLY ASKED 2 TIMES

Ans: Refer Q78. [May-15, (R09), Q4(b) | July-21 (ME), (R18), Q4(a)]

Q9. Derive the expression for power developed due to wind energy. FREQUENTLY ASKED 2 TIMES

Ans: Refer Q97. [May-17, (ME), (R13), Q6(b) | May-17, (EEE) (R13), Q6]

Q10. What are the various methods of storing solar energy?

Ans: Refer Q1. Important Question

Q11. Explain what is meant by Heliostat.

Ans: Refer Q7. Important Question

Q12. What do understand by photovoltaic conversion?

Ans: Refer Q12. Important Question

Q13. Classify different solar energy storage systems and explain them in brief.

Ans: Refer Q39. Important Question

Q14. With the help of schematic diagram, explain the working of solar pond electric power plant.

Ans: Refer Q49. Important Question

Q15. With the help of a schematic diagram, explain solar passive cooling system.

Ans: Refer Q57. Important Question

Q16. Mention the various advantages of wind power?

Ans: Refer Q20. Important Question

Q17. Classify different wind turbine rotors.

Ans: Refer Q26. Important Question

Q18. Why horizontal axis wind turbines are preferred over vertical axis wind turbine?

Ans: Refer Q28. Important Question

Q19. What is Betz limit?

Ans: Refer Q34. Important Question

Q20. Discuss the energy potential from wind in the context of India. Where can wind turbines be installed?

Ans: Refer Q77. Important Question

Q21. Describe horizontal axis type aero generators.

Ans: Refer Q84. Important Question

Q22. Enumerate the types of vertical axis wind turbines.

Ans: Refer Q87. Important Question

Q23. Compare horizontal and vertical axis windmills and briefly list of various types of rotor systems.

Ans: Refer Q93. Important Question

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UNIT 3

BIO-MASS

Syllabus

BIO-MASS: Principles of Bio-conversion, Anaerobic/aerobic digestion, Types of Bio-gas digesters, Gas yield, Combustion characteristics of bio-gas, Utilization for cooking, I.C. Engine operation and economic aspects.

LEARNING OBJECTIVES

On completion this unit, the student shall be able to understand the following concepts.

- Principles of Bio-Conversion
- Concepts of Anaerobic and aerobic digestion
- Types of Bio-gas digesters
- Combustion characteristics of bio-gas
- Bio-gas utilization in cooking and I.C. Engine operation

INTRODUCTION

The green plants produce biomass using photosynthesis in which the plants absorb sunlight, carbon dioxide, and water from the atmosphere. Biomass can also be produced from agricultural waste, animal waste and human waste. It is the renewable energy source and takes less time for its formation. It is one of the important energy sources for any country.

POINTS TO REMEMBER

- **Biomass Energy:** The energy obtained from biomass is called "biomass energy". It is renewable, inexhaustible and indepletable energy.
- **Biomass:** Biomass is defined as the renewable organic matter produced from plants, animals and other organisms.
- **Biogas:** It is a slow burning gas produced by digestion, pyrolysis or hydrogasification.
- **Photosynthesis:** It is a process in which plants convert the light energy of the sun to chemical energy. In this chemical reaction, the water and carbon dioxide, combine to produce glucose using chlorophyll in the presence of sunlight. In this process, the plants absorb carbon dioxide and release oxygen. It is an extremely complex process and can be expressed as,

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

- **Bio-gasifier:** A gasifier is a chemical reactor in which conversion of biomass into gaseous fuel takes place.
- **Methods of Biomass Energy Conversion:** Different methods of obtaining energy from biomass are as follows.
  - (i) Direct Combustion
  - (ii) Thermo chemical conversion
  - (iii) Bio-chemical conversion
- **Anaerobic Digestion:** It is the process in which the organic materials are broken down by micro-organisms in the absence of oxygen.
- **Aerobic Digestion:** It is the process in which the organic material are broken down by micro-organisms in the presence of oxygen.
- The techniques suggested for maintaining the biogas production are
  1. Insulating the gas plant
  2. Composting
  3. Hot water circulation
  4. Use of chemicals
  5. Solar energy systems.
- **Biodiesel:** The liquid fuel extracted from oil seeds (non-edible) that are grown on uncultivated or barren lands is known as Biodiesel.

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PART-A SHORT QUESTIONS WITH SOLUTIONS

Q1. Define biomass and biomass energy.

Answer :

Biomass

Biomass is the combination of two terms, "Bio" refers to living and "mass" refers to weight. Biomass is defined as the renewable organic matter produced from plants, animals and other organisms.

Biomass Energy

The energy obtained from biomass is called "biomass energy". It is renewable inexhaustible and indepletable energy.

Q2. What are the different biomass energy resources and what is the energy yield from each of them.

Answer :

Biomass resources are classified into five types and their list and the energy obtained from them is listed below.

S.No.	Biomass Resources	Energy obtained
1.	Forest	Bio-diesel (Liquid)
2.	Agricultural wastes	Producer gas, solid fuel
3.	Energy crops	Alcohol, bio-ethanol
4.	Aquatic Plants	Biogas or ethanol
5.	Urban waste	Biogas

Q3. Explain with basic equations the concept of photosynthesis.

Answer : April-18, (EEE), (R13), Q1(f)

Photosynthesis is a process in which plants convert the light energy of the sun to chemical energy. In this, chemical reaction, the water (H_2O) and carbon dioxide (CO_2), combine to produce glucose (carbohydrates) using chlorophyll in the presence of sunlight. In this process, the plants absorb carbon dioxide and release oxygen. It is an extremely complex process and can be expressed as,

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Q4. What is anaerobic digestion?

Answer : [May-19, (R15), Q1(f) | Model Paper, Q1(c)]

In this method, biomass is converted into biogas through the decomposition of the bacteria in the absence of oxygen. The biomass used in this process includes animal dung, wet sewage sludge and green plants. In anaerobic digestion, an air tight tank is used to increase the speed of the process. The tank is thermally insulated and consists of a stirrer unit. It takes 10 days for the whole decomposition at a temperature of 35°C. And the biogas which forms above the slurry is collected through the pipes. The leftover residue after the process is highly rich in protein. It is dried and used as an animal feed supplement.

Q5. State the advantages of biomass energy.

Answer :

Advantages of Biomass Energy

1. The wastes may be utilized to produce energy.
2. The fuel used is less expensive.
3. It does not add carbon dioxide to the atmosphere.
4. This form of energy is characterized by the absence of polluting gases like sulphur, phosphorus fumes and fly ash.
5. It helps in saving firewood, leading to conservation of forests.

Q6. Write a short note on Bio-energy.

Answer :

Bio-energy is renewable inexhaustible, indepletable energy derived from carbonaceous waste of various human and natural activities that includes by-products from the wood industry (like wood, wood waste, straw), agricultural crops (sugarcane), raw materials from forest, household waste, manure etc. The energy stored in sugarcane is harnessed to produce biofuel by using bagasse which is the waste material from sugarcane after the sugar has been extracted.

Biofuels or bioenergy derived fuels, are as efficient as the existing energy systems, thereby making it the best substitute for existing transport fuels. Its usage reduces or eliminates all types of air pollution considerably which includes air toxics like carbon monoxide, particulates and hydrocarbons.

Other applications of bioenergy are in cooking, water pumping, power generation and other mechanical gadgets. The employment opportunities generated in bioenergy production involve growing and harvesting biomass, transport, handling and processing operations.

Q7. Present drawbacks of bioenergy. May-17, (EEE), (R13), Q1(f)

Answer :

Disadvantages of Biomass Energy

1. It may lead to soil infertility and erosion.
2. Low energy density, large land requirements
3. Difficulty in transport and storage.
4. Large scale agro-industry may be too complex for efficient operation.
5. Inappropriately designed and integrated systems may produce water and air pollution.

Q8. Write the properties of biogas.

Answer :

Properties of Biogas

1. It has higher calorific value of about 22 MJ/kg-35 MJ/kg
2. It can be compressed and stored at about 115 atm.
3. Minimum ignition temperature is 650°C.
4. The moisture content is 10%-30%.
5. The combustion energy content is 6 kWh/m³ – 6.5 kWh/m³ of raw material.
6. Density of biogas is 1.2 kg/m³.

Q9. What are the uses of biogas?

Answer :

The uses of biogas are as follows.

1. It can be used for direct combustion such as heating, cooking, and drying.
2. It can be used in internal combustion engines for running the tube-well and water pump-set engines.
3. The biogas can be sent through gas pipelines for illuminating the streetlights.
4. Methane can be utilized in the production of methanol.

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Q10. Compare and contrast the biomass and biogas. May-17, (ME), (R13), Q1(b)

OR

What is the difference between biogas and biomass? Explain briefly. May-16, (R09), Q5(a)

Answer :

Differences between Biogas and Biomass

	Biogas		Biomass
1.	It is a slow burning gas, produced by digestion, pyrolysis or hydrogasification.	1.	It is an organic matter produced by plants, animals and other living organisms.
2.	It is obtained when biomass is fermented anaerobically. Biogas mixture contains 55%-66% methane, 30%-40% CO_2 and other impurities like hydrogen sulphide and nitrogen.	2.	Cattle dung, human waste, piggery waste, poultry droppings, kitchen waste, paper waste, etc., are different types of biomass.
3.	Biogas is clean and smokeless. Hence, it is effectively used for cooking, thereby reducing the demand for firewood.	3.	The different biomass resources are burnt directly to get the energy.

Q11. List out the different types of biogas plants. Model Paper, Q1(h)

Answer :

The different types of biogas plants are,

1. Continuous type biogas plant
2. Batch type plant
3. Floating drum type plant
4. Fixed dome type plant.
5. Modified biogas plant.

Q12. What are the advantages and disadvantages of fixed drum type plant?

Answer :

Advantages

1. The cost of fixed drum is low compared to floating drum type, as it uses only cement and no steel.
2. There is no problem of corrosion.
3. As it is constructed beneath the ground, heat insulation is better and the temperature will be constant.
4. Cattle and human excreta and long fibrous stalks can so be fed.
5. It requires no maintenance.

Disadvantages

1. The process of constructing the plant requires skilled personnel.
2. Gas production per cubic meter of the digester volume is less.
3. It has variable gas pressures.

Q13. Write a short note on bio-gasifier.

Answer :

A gasifier is a chemical reactor in which conversion of biomass into gaseous fuel takes place. Various biomass materials like the agricultural waste (stalks, wood wastes, roots of different crops etc.,) are gasified in this equipment.

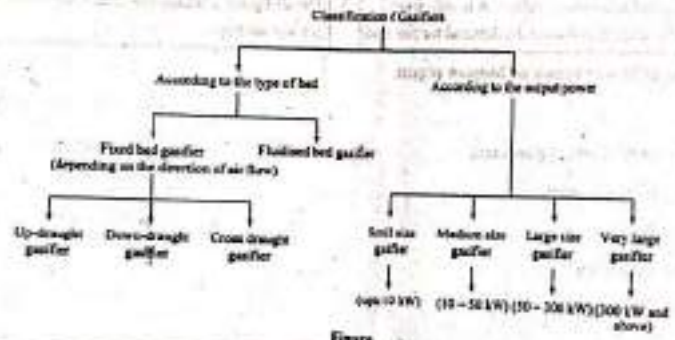
As the biomass flows, many physical and chemical processes take place in the gasifier.

1. Drying
2. Heating
3. Pyrolysizing
4. Partial oxidization
5. Reduction.

The clean fuel consisting of hydrogen and carbon-monoxide is obtained from the gasifier. Its heating value of ranges from 950 kcal/m^3 to 1200 kcal/m^3.

Q14. How are gasifiers classified?

Answer :



Figure

Q15. What are the advantages of using biodiesel as fuel for an I.C engine?

Answer :

Advantages of Biodiesel

1. It causes less pollution as it releases 80% less CO_2 and 100% less SO_2 gases. It is biodegradable.
2. Its Octane number is high when compared to general diesel
3. It is a non-conventional fuel.
4. It has higher flash point.
5. It can be used directly or can be mixed with petrol or diesel in a ratio.

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PART-B ESSAY QUESTIONS WITH SOLUTIONS

3.1 Principles of Bio-conversion – Anaerobic/Aerobic Digestion

Q16. Explain the origin of biomass energy?

Answer :

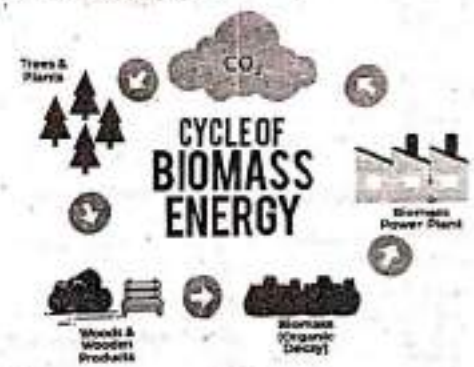
Origin of Biomass

The origin of biomass is the green plants. They produce biomass using photosynthesis in which the plants absorb sunlight, carbon dioxide and water from the atmosphere. Biomass can also be produced from agricultural waste, animal wastes and human waste. It is the renewable energy source and takes less time for its formation. It is one of the important energy sources for any country. It consists of chemical energy which is obtained from the sun and is also considered as a form of solar energy since it can be again used to grow the plants.

Biomass resources are of three types,

1. Heating the biomass directly to get heat energy
2. processing it into liquid and gaseous fuels
3. Conversion of biomass to biogas.

In many countries such as Japan and Canada biomass is the major energy source for eating, cooking and various other household works. They also generate electricity using biomass.



Figure

Q17. Discuss what are the biomass resources available for production of biomass energy.

April-14, (R09), Q6(a)

OR

Explain in brief about different biomass resources.

Sep.-20, (R16), Q7(a)

Answer:

Biomass Resources

Biomass resources are classified into five types. They are,

1. Forest
2. Agricultural wastes
3. Energy crops
4. Aquatic plants
5. Urban waste.

1. **Forest**

Forests are the rich source of fuel, wood, charcoal and produces gas.

2. **Agriculture Wastes**

Crop residues such as straw, rice husk and waste wood are pressed to form lumps, known as fuel pellets and are used as solid fuel.

3. **Energy Crops**

Sugarcane, sweet sorghum, sugar beet, starch plants, cassava, oil producing plants are used as bio-resources.

4. **Aquatic Plants**

The water plants which provide raw materials for producing biogas or ethanol are water hyacinth, kelp, seaweed and algae.

5. **Urban Waste**

Urban wastes are of two types,

(i) Municipal Solid Waste (MSW)

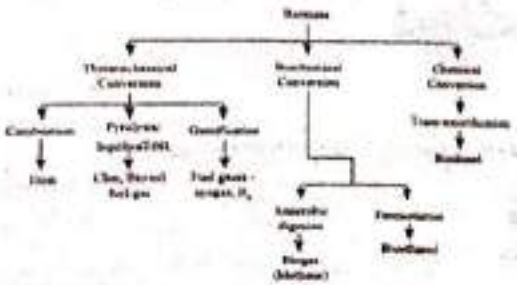
(ii) Sewage (liquid waste).

Energy from MSW can be obtained from direct combustion (incineration) and from sewage, biogas can be obtained after some processing.

Q18. Discuss the possible energy conversion routes and products from biomass.

Answer : July-21, (ME), (R16), Q6(a)

The possible energy conversion routes and products from biomass are shown in below flow chart.



Figure

Q19. What are the advantages of biomass conversion into biogas? Discuss.

Answer : May-18, (R15), Q7(a)

Biogas is a versatile fuel. It is mainly used for cooking purpose to replace burning of firewood, agricultural residues and dung cakes. It is also burnt for lighting purpose to replace kerosene.

Biogas Slurry

Indian designs of biogas plants are based on cattle dung and produce fermented material in the form of slurry. It is commonly used to compost other organic residues in pits. The composted material is then applied in the agricultural fields as manure. Many times the slurry is dried and then used as manure. Some of the farmers apply it in the same form also on a limited scale. The slurry is used in pisciculture also.

The biogas slurry gives better response to crops than other bulky organic manures. The economic viability of a biogas plant also depends upon the optimum use of biogas slurry.

Biogas as a Fuel

Biogas can be used to operate both CI and SI engines. CI engines can run on dual fuel (biogas + diesel) and pilot injection of diesel is necessary for igniting the mixture of air and biogas inside the cylinder. However, the initial starting of diesel engine is done on pure diesel. Spark ignition engines can be operated on biogas after starting on petrol. Therefore, it is economical to use it for IC engines.

Q20. How do you produce biogas and explain its methods in detail.

April-14, (R13), (R15), Q7(a)

OR

How biomass conversion takes place?

Answer : Model Paper, Q8(a)

Methods of Biomass Energy Conversion

The different methods of obtaining energy from biomass are as follows,

1. Direct combustion
2. Thermo chemical conversion
3. Bio-chemical conversion.

1. **Direct Combustion :** Combustion is a process of burning the biomass to generate heat which is used for cooking, industries, generation of electricity and to obtain by-products. Combustion of products is related to all the fuels, i.e., solids, liquids and gases. But, combustion of biomass is difficult compared to other fuels because of the moisture content present in it.

Combustion takes place in the following two forms.

(i) **Incineration :** The method of burning completely to ashes is called incineration. This method is especially employed for burning municipal solid wastes in order to reduce the volume of it and to generate steam and electricity.

(ii) **Pyrolysis :** The products obtained from this process are biochar, charcoal, bio oil, gases like methane, carbon monoxide, hydrogen and carbon dioxide. Solids are produced at low temperatures and gases are produced at high temperatures. Based on the time taken, the process is classified into slow pyrolysis and fast pyrolysis.

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2. **Thermochemical Conversion :** It is a process in which biomass is decomposed at varying combinations of pressures and temperatures.

Thermochemical conversions are of two types.

(i) **Gasification :** It is the process of converting biomass directly into energy. The biomass is heated with a controllable amount of oxygen to produce low heating value gas. Also it can be reacted with steam and oxygen at high temperature and pressure to produce medium heating value gas. The resulting gas is called producer gas which is used in producing heat and steam and also used in generating electricity.

(ii) **Liquification :** Liquification is a process of heating of solid biomass in the absence of oxygen to produce a liquid fuels. It is performed at low temperatures and high pressures. The products obtained from the process such as the producer gas and the pyrolytic oil can be used as fuels, as they are cheaper and more efficient than the solid biomass.

3. **Biochemical Conversion :** Biochemical process involves conversion of biomass to biofuels. It is a slow process as it is carried out at low temperatures.

Biochemical conversions are of two types. They are,

(i) **Anaerobic Digestion**

For answer refer Unit-III, Q4.

(ii) **Fermentation :** It is a process of decomposition of organic matter by ferments like bacteria, yeast, enzymes, etc., in the absence of oxygen. This process is mostly used for the conversion of grain and sugar crops to form ethanol.

Q21. Explain with a neat sketch the working of thermo chemical conversion of biomass.

Answer : July-21, (ME), (R16), Q6(a)

For answer refer Unit-III, Q20, Topic : Thermochemical Conversion.

Q22. What is meant by wet processes and dry processes?

Answer :

Wet Processes

Wet processes refers to the process which consists of dry matter waste in least amounts.

The following are the three types of wet processes.

1. Anaerobic digestion
2. Fermentation
3. Chemical reduction.

1. **Anaerobic Digestion**

For answer refer Unit-III, Q4.

2. **Fermentation**

In this process, the sugar solution is fermented by natural yeasts to obtain ethanol. The brew after the fermentation process consists of alcohol in small amounts which can be separated by distillation. Crops like maize and wheat grain, sugar cane produced by vegetable starches are made into powders and heated with enzymes to obtain starch for producing fermentable sugars. Fermentation of cellulose materials like wood, straw, paper waste etc., requires a pre-treatment process and hydrolysis with hot acid. The residues from sugarcane bagasse is burnt to obtain heat. The final residue after the process is rich in protein and is used as cattle feed supplement.

3. **Chemical Reduction**

Among all the wet processes of biomass conversion, chemical reduction is the least developed. The process generally consists of cooking of animal wastes or plant slurry with an alkaline catalyst at temperatures between 250°C and 400°C in the presence of carbon monoxide at a certain pressure. With this, the organic matter is converted into a mixture of oils. The calorific value can be increased by increasing temperature and decreasing pressure.

Dry Processes

This process consists of dry matter wastes in considerable amounts.

The different dry processes are,

(i) Pyrolysis

(ii) Liquefaction

(iii) Gasification

(iv) Steam gasification

(v) Hydrogenation.

(i) **Pyrolysis**

It is a process, which takes place under the action of heat. This process is irreversible chemical process and also occurs in absence of oxygen. The heat energy is used to split the chemical bonds. Reactions are complex and pyrolysis of human and animal waste produces C_2H_4, C_2H_6, C_3H_8, CO_2, CO, H_2 etc. The process produce solid, liquid or gaseous fuel.

Dry woody matters and wood-chips can be pyrolysed to produce a wide range of energy rich fuels. In this process, heating of material which is fed in pulverised form is carried out in reactor vessel in the absence of air. With the rise in temperature of material, the lignin and cellulose present breakdown into simpler substances. These substances are then driven off leaving a char residue behind.

(ii) Liquefaction

In this, the feed stock (raw material) is heated rapidly at low temperatures to maximize the yield. Due to this heating, the vapour gets condensed from the gas stream and separates into two phases. One is aqueous phase and the other is non-aqueous phase. Aqueous phase consists of a soup of water soluble organic materials whereas non-aqueous phase consists of oil and tars. These products are improved to premium fuels using refining techniques or can be burnt directly with some difficulty.

(iii) Gasification

To increase the gas yield from pyrolysis of wet biomass, small quantity of air or oxygen is blown into the reactor vessel and the temperature is increased beyond 1000°C. Due to this increase in temperature, a part of feed is burned. The gas obtained from the oxygen-fed system has a calorific value of 10-20 MJ/m^3 and that from the air blown gasifiers has a calorific value of 5 MJ/m^3. The gas thus obtained can be burnt or can be converted into substitute natural gas.

(iv) Steam Gasification

Woody matter is processed with hydrogen gas at high temperature and pressure to produce methane. The hydrogen required can be produced in the reactor vessel itself from carbon monoxide and steam. However, the steam gasification is the most efficient method to produce methanol. The energy yield around 55% can be achieved by this process.

(v) Hydrogenation

It is a process in which heavy oils are produced and refined to premium fuels by reacting steam and carbon monoxide with cellulose at temperature range of 300°C - 400°C and pressure of about 100 atm.

Q23. Explain the process of photosynthesis. What are the conditions, which are necessary for it?

Answer :

Photosynthesis is a chemical reaction that generally takes place in green plants in the presence of sunlight and chlorophyll. In this, the reaction takes place [illegible] n water and carbondioxide (CO_2), which leads to splitting of these molecules and production of carbohydrates with the release of pure oxygen. This photosynthesis process is extremely complex process and can be expressed as,

$$CO_2 + H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} (H_2CO)_n + O_2 + \text{chlorophyll sugar}$$

(or)

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

There are two important phases in this process.

Phase 1 : The water molecule splits into H_2 and O_2 in the presence of sunlight and chlorophyll. This is the photolysis of the water. The oxygen escapes into the atmosphere whereas the hydrogen turners into an unknown compound

Phase 2 : This phase does not need sunlight and it is a dark reaction. In this phase, hydrogen combines with the carbon dioxide to form sugar or starch.

Conditions required for Photosynthesis

1. **Light :** It is the most important source for photosynthesis. Radiations between 400 – 700 Å. These radiations are known as photo-synthetically active radiations (PAR) is used by plant, but only a part of this energy is actually consumed in this process. The upper limit of photosynthesis efficiency is about 5%.

2. **Carbondioxide (CO_2) Concentration :** The carbondioxide (CO_2) is important in photosynthesis process, as it reacts with H_2O, to produce required energy i.e., starch or sugar. The concentration of CO_2 in atmosphere is about 0.03% but it is gradually increased due to the human activities. The main resources of carbon dioxide are respiration of living beings, oceans, decay of organic matter and combustion of fuels.

3. **Temperature :** The photosynthesis process depends upon the temperature takes places between 0°C to 60°C. The biochemical part which is controlled by enzymes is highly effected and is sensitive to temperature. The photo chemical part has no effect due to temperature.

Q24. Explain the method for converting biomass into ethanol with a neat sketch.

Answer : [July-21, (EEE), (R14), Q7(a)] [Model Paper, Q7(a)]

Various Biomass Sources for Producing Alcohol

Generally, the organic matter which contains sugar is used for production of alcohol (ethanol). Some of them are.

1. **Sugars**

   Examples: Cane sugar, grapes, sugar beet, fruits, mollases etc.

2. **Starches**

   Examples: Gains (barley), potatoes, root crops (cassava) etc.

3. **Cellulose**

   Examples: Wood, grasses, crop residue etc.

Ethanol Production from Sugars

This includes the following processes,

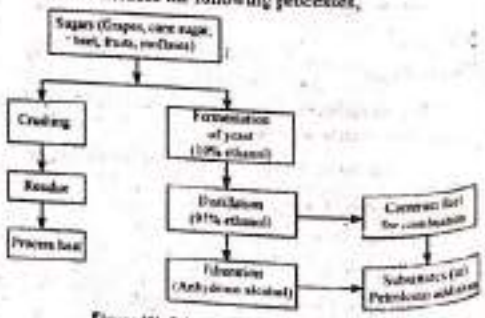

Figure (1): Ethanol Production from Sugar

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Ethanol Production from Starch

The processes involved in ethanol production from starch are,

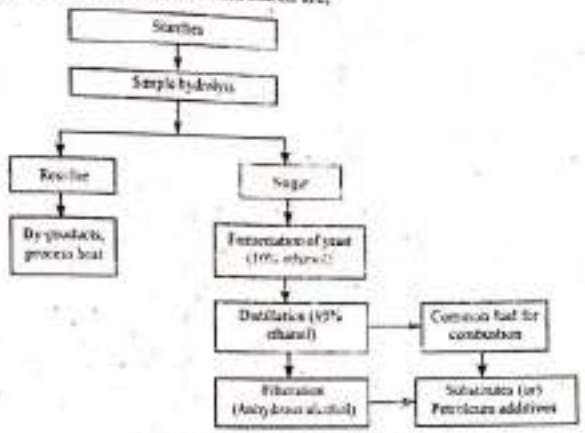

Figure (2): Ethanol Production from Starch

Ethanol Production from Cellulose

The following flow diagram shows various processes involved in producing ethanol from cellulose.

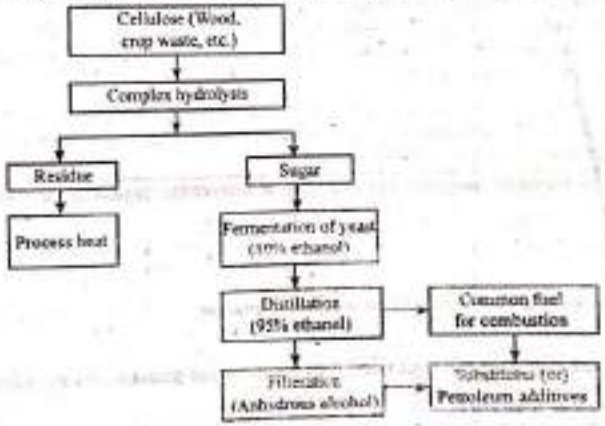

Figure (3): Ethanol Production from Cellulose

Q25. Explain the process of power generation from urban waste using incineration plant with a neat sketch.

OR

Explain the process of extracting energy for municipal solid waste.

Answer : [July-21 (EEE), (R14), Q7(b)]

Waste-to-Energy Incineration Plant

An incineration plant is commonly stated in the forests or near industries where there is a source for solid waste. This is because to eliminate transport expenses of raw material. By this plant, waste disposal problem is reduced to a large extent as it utilises the waste and only small amounts of ash or residue is released. By incineration process, waste is converted to electrical power and in addition it provides heat energy which can be used as process heat. The operation of waste-to-energy plant is similar to that of a conventional power plant.

The process of incineration can be clearly explained by waste-to-energy incineration plant as shown below.

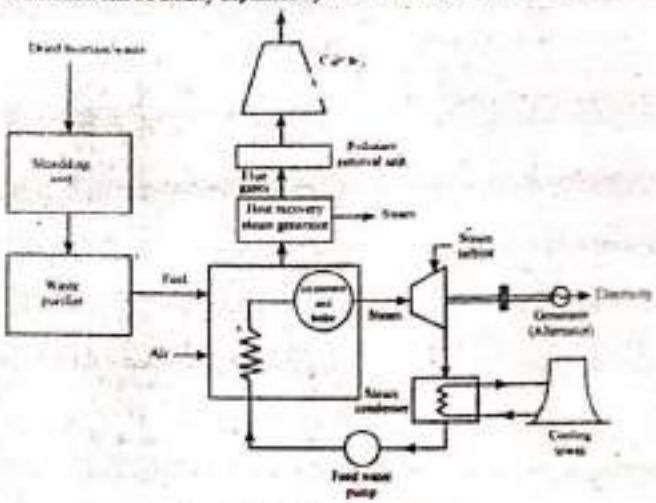

Figure: Waste-to-energy Incineration Plant

The waste from industries or forests is collected, stored and dried for few days. The dried biomass is made into smaller pieces in shredding unit. In waste purifier, a stream of air separates the heavier particles like metal and glass and obtains fuel (Refuse derived fuel) that is used for burning in the furnace. Steam is produced in the boiler by burning the fuel at 1000°C. If the fuel is not able to burn completely, then a specific amount of alternate fuel is used. On combustion of fuel, super-heated steam is produced in the boiler. This steam is passed on to a steam turbine where it expands and operates the alternator connected to it. Then electrical power is generated in the alternator.

A heat recovery generator is used to generate higher possible amount of heat from the flue gases released from boiler. The exhaust (flue) gases are released to the atmosphere by passing them through a pollutant removal unit. In this unit, the gases are made free from pollutants like NO_x, SO_x, particulates, etc.

Q26. Explain with the schematic diagram the working of anaerobic digestion showing input material and effluents.

June-11, (R13) Q5a

OR

Discuss about the energetic involve in anaerobic digestion.

May-11, (R09) Q5a

OR

Explain in detail about anaerobic digestion and the different phases and the processes involved in it.

OR

Explain with a neat sketch the working of anaerobic digestion process.

Answer :

July-21 (MEL) (R16) Q7a

Anaerobic Digestion

It is the process in which the organic materials are broken down by micro-organisms in the absence of oxygen. This process produces gas usually containing methane (CH_4) and carbon dioxide (CO_2) with minimum impurities. The process is carried out at low temperature upto 65°C with moisture content minimum of 80%. The gas produced by this process can be burned directly and can also be converted to synthetic natural gas by removing carbon dioxide and impurities from it. The residue of the process is rich in protein and is also used as a cattle-feed supplement.

Anaerobic digestion takes place in three stages,

1. Enzymatic hydrolysis
2. Acid formation
3. Methane formation.

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1. **Enzymatic Hydrolysis**

The process in which complex compounds like fats, proteins and carbohydrates are broken down into small compounds.

$$\underbrace{(C_6H_{10}O_5)_n + n(C_6H_{12}O_6)}_{\text{(Cellulose + nutrients)}} \xrightarrow{\text{Enzymes}} \underbrace{n(C_6H_{12}O_6)}_{\text{(soluble glucose + nutrients)}}$$

2. **Acid Formation**

The process of converting soluble glucose and nutrients into volatile fatty acids like acetic and propanic acid is called as acidification. The acid forming bacteria gives 70 percent of methane by product.

Reaction of Acidification

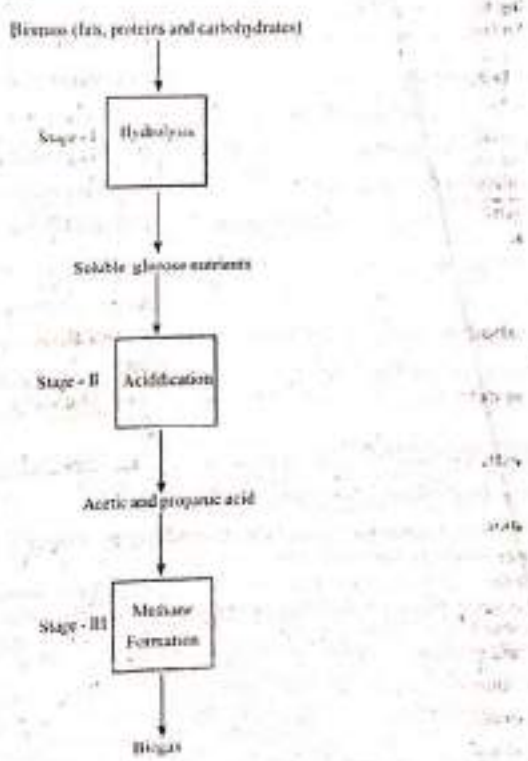
$$C_6H_{12}O_6 \xrightarrow[\text{Bacteria}]{\text{Acid producing}} \underset{\text{(ethyl alcohol)}}{2CH_3CH_2OH} + 2CO_2 + \text{Fatty acid} + H_2 + \text{Other products}$$

3. **Methane Formation**

In this stage, with methane as an important element, the methane producing bacteria converts the organic acid into biogas.

Reaction of Methane Formation

$$2CH_3CH_2OH + CO_2 \xrightarrow[\text{Bacteria}]{\text{Methane producing}} 2CH_3COOH + CH_3CH_2COOH \longrightarrow \underset{\text{(methane)}}{CH_4} + CO_2$$



Figure

Q27. Discuss about the anaerobic digestion and the factor helping the anaerobic digestion with the factors affecting the anaerobic digestion. Name the various models of biogas plant.

Answer :

Anaerobic Digestion

For answer refer Unit-III, Q26

Models of Biogas Plant

For answer refer Unit-III, Q11.

Q28. What is the difference between aerobic digestion and anaerobic digestion? July-13, (R15), Q1(a)

OR

What is aerobic digestion? Differentiate between aerobic and anaerobic digestion.

Answer :

Aerobic Digestion

Bacteria which grows in presence of oxygen is called aerobic bacteria. Aerobic fermentation can be used to decompose organic matter. CO_2, NH_3 and small amounts of other gases are produced during aerobic digestions. It is used to produce the hygienic material and to recover the plant nutrients for reuse in the fields.

Difference between Aerobic and Anaerobic Digestion

	Aerobic Digestion		Anaerobic Digestion
1.	It takes place in the presence of oxygen.	1.	It takes place in the absence of oxygen.
2.	Amount of sludge produced is high.	2.	Amount of sludge produced is low.
3.	It requires pumping of large quantity of air.	3.	It does not require pumping of air.
4.	Sludge has less fertility contents.	4.	Sludge has high fertility contents.
5.	The output product is Carbondioxide.	5.	The output product is methane.
6.	Reaction rate is high, hence it requires long time.	6.	Reaction rate is low, hence, it requires less time.
7.	Odour emission is high.	7.	Odour emission is low.
8.	High operating cost.	8.	Low operating cost.
9.	Low initial cost.	9.	High initial cost.
10.	It can work only on dry waste.	10.	It can work on dry waste and wet waste.
11.	Area required is large.	11.	It requires less area.
12.	Treatment of output is not required.	12.	It requires post treatment.

3.2 Types Of Bio-Gas Digesters, Gas Yield

Q29. What are the techniques suggested for maintaining the biogas production?

Answer :

The techniques suggested for maintaining the biogas production are,

1. Insulating the gas plant
2. Composting
3. Hot water circulation
4. Use of chemicals
5. Solar energy systems

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Insulating the Gas Plant

1. In this method, the outer surface of the digesters are coated with various materials such as aluminium cladding, fibre, mineral wool, glass, straw, etc., to reduce the escape of heat from the digester. A Janata type biogas plant is generally built under the ground, in order to reduce heat losses.

Composting

2. This method is performed to elevate the digester operating temperatures, by utilising the heat produced during aerobic composting of agricultural residues.

In composting, the slurry is heated by the exothermic reaction of the compost. During the process, the loss of released heat radiation from the top of the digester a restricted by insulating the top of the gas holder by thick paddy straw mat. Composting is considered to be the most inexpensive method for producing large amount of biogas during winter.

3. **Hot Water Circulation**

In this method, hot water is circulated through the system, in order to maintain the fermented slurry temperatures upto the required level. It is considered to be an efficient process, but the system cost of this process is high.

4. **Use of Chemicals**

Chemicals like urea and urine are used to increase the digester temperature. For example, animal urine is used to improve the biogas production.

5. **Solar Energy Systems**

Solar heat is utilized by the biogas digester by the following two means,

(i) **Active System**

In this, the digester feed is directly heated by the solar energy during the day and once it achieves the required temperature, the feed is fed to the digester.

(ii) **Passive System**

This is an indirect method of utilizing solar heat by constructing a green house around the digester, in order to collect the radiant heat energy which is further used by the biogas digester.

Q30. Discuss with sketch the working of a fixed dome biogas plant.

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

OR

Classify biogas plants and explain any one of them.

Answer :

Biogas plants are classified as,

(i) Continuous type biogas plant
(ii) Batch type plant
(iii) Floating drum type plant
(iv) Fixed dome type plant
(v) Modified biogas plant.

Fixed Dome Type

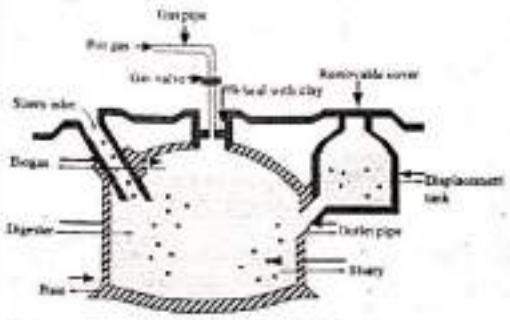

Figure: Chinese Biogas Plant

Chinese biogas plant or Janata type is a fixed dome type biogas plant. It consists of a fixed dome made of masonry. An inlet is provided for the deposition of the various waste products into the dome. Degradation of the deposited waste products forms a slurry. The dome is closed with a removable manhole cover sealed with clay. Due to the rigidness of the dome, gas is produced which exerts pressure on the surface of the slurry. Thus, the slurry is displaced into a displacement tank through an outlet pipe. Height of the slurry in the displacement tank must not exceed 1000 mm from the surface of the slurry in the dome. This finally leads to a significant variation in the pressure of stored gas. Thus, the plant needs regular inspection. Biogas produced in the dome is taken to use, through a gas pipe with a valve to regulate the flow of gas.

The design of Chinese biogas plant is simple and cheaper. Steel required in its construction is comparatively less and hence reduces the expenses. Construction of leak proof masonry domes require skillful masons.

Q31. With the help of a neat diagram, explain about continuous and batch type biogas plants.

Answer :

Continuous Type Biogas Plant : In the continuous type plant, the raw material is charged regularly in a single digester and the process continues without any obstruction. In this, the raw material is effectively blended with the digesting mass and the gas production is maintained properly. This process can be completed in one or two stages.

1. **One Stage (or) Single Stage Process :** In this process, the conversion of organic compounds into biogas is carried out in a single chamber. The raw material is fed regularly in the chamber, while the waste sludge moves out from the outlet. The agriculture residues may cause adverse effects, when they are fermented in a single stage process.

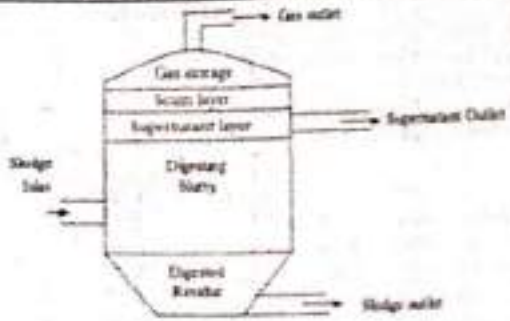

Figure (1)

2. **Two Stage (or) Double Stage Process :** In this process, the acidification stage and methanogenic stage are carried out in two individual chambers. Therefore, the acid formation is completed in first chamber and the dilute acids formed are fed to another chamber. In second chamber, the dilute acids are converted into biogas, which can be collected from the gas outlet.

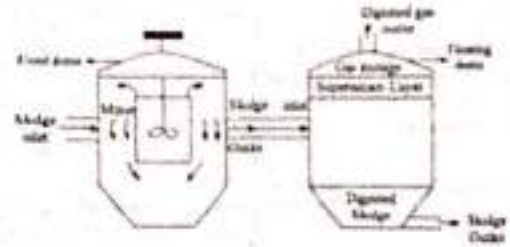

Figure (2)

The basic advantages associated with continuous process are,

1. Small size digestion chambers are sufficient to produce biogas.
2. Requires less time for digestion
3. Continuous production of gas is possible
4. Easier in operation.

Batch Type Biogas Plant : In batch type biogas plant, the feeding is carried out in intervals. Hence, the plant is periodically charged and emptied. The digesters which are charged with lime, urea, etc., produces gas for about 40-50 days. After the completion of digestion, the plant is emptied and the fresh charge is fed. This process maintains regular supply of gas. This plant is expensive and is to be operated on commercial basis to make it economical. These plants are best suited for working with long fibrous materials and it is necessary to add fermented slurry, in order to initiate the digestion of biomass.

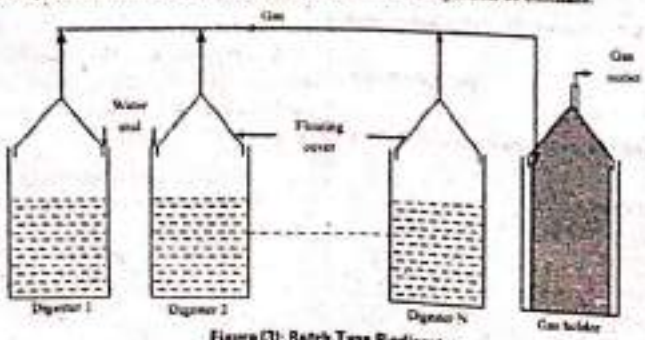

Figure (3): Batch Type Biodigester

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Q11. What is a community biogas plant? What are the main problems encountered in its operation? 1r

Answer :

[May-17, (R13), Q7(a) | Model Paper, Q6(b)]

Generally, biogas plants are developed based on separate family unit and community plant. Community biogas plant is only based on the cow dung and other organic waste in rural areas. It can be used to generate significant amount of biogas in organized way. It helps in transforming village life by providing efficient working fuel and electricity for lighting, operating small industries, irrigation, supplying drinking water, maintaining sanitation, etc. The various problems encountered in operating community biogas plant depends upon three main factors. They are,

1. Social factors
2. Managerial factors
3. Technical factors

1. **Social Factors**

It considers the problems related to consequences of community plants compared to other rural projects. It also involves the society's conception with respect to their use as fuel generation or waste treatment device. It also involves issues related to the total contribution of community in its operation.

2. **Managerial Factors**

Managerial factors deal with operation and maintenance of plant, distribution and pricing of gas and digested manure, gathering of feed materials for plant operation. It also considers the water supply for slurry preparation and funds mobilization when plant is running under more complications.

3. **Technical Factors**

The main technical problem includes the design of pipeline for supplying the gas when in a colony many houses are distributed widely then issuing of biogas through pipelines may cause economic difficulty. Hence, pipelines should be designed appropriately in order to supply the gas without any difficulty.

Q12. With the help of a neat diagram, explain the construction and working of floating drum type bio-gas plant.

July-13, (R10), Q7(a)

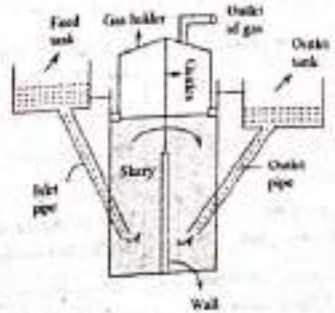
OR

Explain the constructional details and working of KVIC digester with the help of a neat diagram. Write the applications of biogas.

Answer :

The floating dome type biogas plant is also known as KVIC digester plant.

KVIC (Khadi and Village Industries Commission) digestion plant is the most commonly used floating drum type biogas plant. The digester is also called as fermentation tank. It is a pit made of masonry having diameter ranging from 1.3 m to 6 m and wall depth from 3 m to 6 m. It consists of biomass feed tank, gas holder, central guide pipe and outlet tank, as shown in figure.



Figure

A wall is constructed in the middle of the digester, which divides it into two compartments. This partition wall facilitates the circulation of the slurry. The partition wall is submerged in slurry, when the two compartments of the digester is full. The feed tank also known as inlet tank, is located at the surface level. The dung and water are mixed in the ratio 4:5 and this mixture is called slurry. This slurry is fed to the digester with the help of pipe connecting from feed tank to the digester known as inlet pipe.

The digester can hold the raw material for 60 days. Outlet tank is located slightly below the feed tank level. When the digester is full and if more slurry is added, then the equal amount of slurry flows out with the help of the pipe connecting from digester to outlet tank known as outlet pipe.

A mild steel drum is placed on the top of the digester and is known as gas holder. Its function is to collect the biogas produced from digester. A pipe is provided at the top of the holder for flow of gas. The gas holder maintains constant pressure inside the tank by moving up and down with the help of central guide pipe which is fitted to the frame at the bottom. The pressure inside the tank increases and gas holder moves up, so that the pressure is maintained constant. The pressure of gas in KVIC digester is about 7 cm to 9 cm cm of water column. This pressure is sufficient to carry it upto a length of 20 m to 100 m depending on the size of the plant.

The cost of the gas holder is 40% of the total plant cost. It requires anti-corrosive paint coating from time to time, in order to improve the efficiency of the plant.

Advantages

1. The pressure inside the digester is constant.
2. Biogas and external air are not in contact with each other. Therefore, there are no explosion problems.
3. There is no leakage problem.
4. Scum (material floating on top) problem is reduced.

Disadvantages

1. Maintenance cost is high.
2. Heat loss may be possible through gas holder.

Q34. Compare the floating drum and fixed dome type biogas plants.

Answer :

	Fixed Dome Type Plant		Floating Drum Type Plant
1.	It can be constructed above or underneath the ground.	1.	It can be build only below the ground level.
2.	It has regular fillings and irregular discharges.	2.	It has regular fillings and regular discharges.
3.	The main cost factor of this plant depends on bricks and cement.	3.	The main cost factor of this plant depends on bricks, cement and steel.
4.	The digestion period for this type of plant is about 30-60 days.	4.	The digestion period for this type of plant is about 40-60 days.
5.	It is cheaper in cost.	5.	It is expensive due to steel.
6.	For this type of plant, special treatment is required to the gas storage dome for the gas tightness.	6.	There is no need of such treatment for this type of plant.
7.	The temperature and heat insulation is uniform throughout the system, due to underground construction.	7.	In this type of plant, heat is liberated through the gas holders, hence, it is not suitable for cooler regions.
8.	The raw materials required for fixed dome type plant are agricultural waste, organic matter, animal and human faeces.	8.	The raw materials required in floating drum type plant are animal and human faeces, chopped agricultural wastes as an addition.

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Q35. What are the advantages and disadvantages of floating drum plant.

Answer :

Advantages

1. The pressure of the gas released is constant or stable.
2. There is no formation of dirt on the surface of the slurry as the solid particles are always submerged into the liquid.
3. There is no need of external pressure devices, when the water is added or the slurry is taken out from the tank.
4. The production of the gas per cubic metre of the total volume of the digester is high.
5. There is no danger of gas leakage in the plant.
6. The plant can be prevented to some extent form exploding, if the oxygen is mixed with the gas.
7. The scum in the slurry can be crushed by the rotation of the drum with the help of welded braces.

Disadvantages

1. Highly expensive as the cost of gas holder itself is about 40% of the entire plant.
2. Loss of heat from the gas holder.
3. These plants are problematic in colder regions and periods.
4. The plant should be frequently maintained by painting the holder once or twice in a year.
5. UV rays damages the pipe which connects the main gas pipe to the holder. Hence, it requires regular check.

Q36. Discuss the parameters that affect the performance of biogas digester.

April-14, (R09), Q6(b)

OR

Explain any six factors affecting bio-digestion of gas.

Answer :

The various factors which affect the bio-digestion of gas are as follows.

1. **pH Value**

The best range for anaerobic digestion is within a pH range of 6.8 to 8.0. The pH in a biogas digester is also a function of the retention time. The introduction of raw material will often lower the pH value and make the mixture more acidic. The methanogenic bacteria are very sensitive to pH and do not develop below the value of 6.5. A toxic effect on methanogen population will be seen if the pH value is higher than 8.5.

2. **Loading Rate**

It is the rate at which the amount of raw materials fed per unit volume of digester capacity per day. In some conditions, about 6 kg of dung per m^3 volume of digester is recommended in case of a cow dung plant. If the plant is overfed, acids will accumulate and methane production will be inhibited.

3. **Heavy Metals**

The heavy materials such as stones, Cu, Cr, Fe, Pb, etc., should be removed from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of the digester will decrease as these metals settle down at bottom as well as sometimes produce poisonous effect on bacteria.

4. **Volatile Solids**

The gas production varies proportionally with the volatile solid content in a unit volume of fresh dung.

5. **Stirring**

It is always important to stir because, if the slurry is not stirred, it will tend to settle out and form a hard scum on the surface, which will prevent release of the biogas.

6. **Carbon-Nitrogen Ratio**

In an organic materials, the relationship between the amount of carbon and nitrogen present can be expressed in terms of carbon-nitrogen ratio. The loss of fertilizer quality or even methane content can be prevented by using the correct ratio of carbon to nitrogen. The carbon-nitrogen ratio ranging from 20 to 30 is the optimum ratio for anaerobic digestion. The nitrogen will be consumed rapidly by methanogens for meeting their protein requirement whenever the carbon-nitrogen ratio is very high. This will result in breakdown of the reaction on the left over carbon content of the material.

Q37. Write short notes on biogas.

Nov./Dec.-18, (R13), Q14(b)

OR

What is biogas? Explain the process for generating biogas.

Answer :

Biogas is an inexpensive source of renewable energy made from anaerobic digestion of the organic waste material i.e., agricultural waste (straw, plant, leaves, algae, bagasse, paddy, husk, water weeds, water hyacinth, de-oiled castor cakes, food waste, etc.,) animal waste (manure from animal processing units, example, pig, cattle, chicken, human or farm waste). Mostly, any cellulose biodegradable is a suitable raw material for biogas production, biogas is a clean, slow burning gas used for cooking.

The major constituents of biogas are, any cellulose organic material of animal or plant origin which is easily biodegradable is a suitable raw material for biogas production. Biogas is a clean, slow burning gas used for cooking.

Methane CH_4 – 50% – 70% – or more by volume

Carbondioxide CO_2 – 30% – 40%

Hydrogen H_2 – 5% – 10%

Nitrogen N_2 – 1% – 2%

Water vapour H_2O – 0.3%

Hydrogen sulphide H_2S – Traces

The calorific value of $1m^3$ biogas is about 6000 watts per hour equivalent to half litre of diesel oil. Biogas is environmentally friendly alternative fuel and the best substitute for kerosene, natural gas, butane, coal and other materials that come from fossils.

The process involved in generating biogas from biomass involves various steps as follows.

1. The slurry is prepared by mixing dung and water in the ratio of 4 : 5.
2. The slurry undergoes digestion. It is a biological process which occurs in the presence of anaerobic organisms and in the absence of oxygen.
3. Digestion process undergoes at ambient pressure and at temperature range of 35 – 70°C.
4. Anaerobic organisms which takes part in digestion are microscopic living organisms. They are bacteria, fungi, virus etc., of beneficial or non-harmful type.
5. The biogas is generated when fermentation takes place through anaerobic digestion.

The process of digestion takes place in a special construction, named as biogas digester. It is generally constructed below ground level. Diameter and depth of a biogas digester lies with in the ranges of 1.5 m to 6 m and 3 m to 6 m respectively.

The construction of a digester is shown in the following figure.

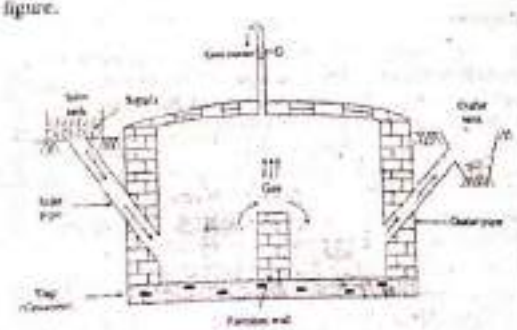

Figure : Biogas Digester

Q38. Explain the advantages and uses of Biogas.

July-21 (ME), (R16), Q7(b)

Answer :

Advantages of Biogas

The advantages of biogas are.

1. It is an environment-friendly method of energy production.
2. It is a free source of energy that can be compressed to power the vehicles.
3. Production of biogas does not require technical expertise.
4. Needs low maintenance.
5. Decrease in the indoor air pollution.
6. Reduction in deforestation and soil erosion. It reduces the dependence on firewood from the forests.
7. Decrease in greenhouse gas emissions and limits global warming.
8. The time taken for cooking is less when compared with cooking using firewood.
9. The slurry can be utilized in the production of manure as it is rich in nutrients (nitrogen and phosphorus) for the plants.
10. Improved hygiene of the surrounding environment since the excreta are directed to pathogen destroying digestion tanks of the system.

Uses of Biogas

For answer refer Unit-III, Q43.

Q39. Describe the working of floating dome type biogas plant and state its advantages.

June-18, (R13), Q4(b)

Answer :

Working of Floating Dome Type Biogas Plant

For answer refer Unit-III, Q33.

Advantages

For answer refer Unit-III, Q35, Topic: Advantages.

Q40. Describe the process of bio-gas generation and factors affecting the generation of biogas.

Dec.-20, (R18), Q7

Answer:

Bio-gas Generation

For answer refer Unit-III, Q37.

Factors Affecting Bio-gas Generation

For answer refer unit-III, Q36.

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Q41. Classify biogas plants and discuss the parameters that affect the performance of biogas digester.

Sep.-22, (R18), Q7(b)

Answer:

Classification of Biogas Plants

For answer refer Unit-III, Q11.

Parameters Affecting the Performance of Biogas Digestor

For answer refer Unit-III, Q36.

Q42. The following data are given for a family biogas digester suitable for the output of 8 cows, the retention time is 15 days, temperature is 35°C, the dry matter consumed per day is 2.5 kg and the biogas yield is 0.28 m³ per kg. The efficiency of the burner is 65% and methane proportion is 0.7, and the heat combustion of methane is 28 MJ/m³. Calculate the volume of the biogas digester and the power availability from the digester.

Answer :

Given that,

Dry matter consumed by eight cows,

$M = 2.5 \text{ kg/day} \times 8 = 20 \text{ kg/day}$

Retention time, $t_r = 15$ days

Temperature, $T = 35°C = 35 + 273 = 308$ K

Yield of the biogas, $C = 0.28 \text{ m}^3/\text{kg}$

Efficiency of the burner, $\eta = 65\% = 0.65$

Methane proportion, $F_m = 0.7$

Heat of combustion of methane, $H_m = 28 \text{ MJ/m}^3$

Assume,

Density of methane, $\delta_m = 30 \text{ kg/m}^3$

Volume of the biogas digester

Volume of the fluid, $V_f = \frac{m}{\delta_m}$

$= \frac{20}{30}$

$\therefore \quad V_f = 0.666 \text{ m}^3/\text{day}$

Volume of the digester, $V_d = V_f \times t_r$

$= 0.666 \times 15$

$\therefore \quad V_d = 9.99 \text{ m}^3$

Volume of biogas, V_b = (Biogas yield) × (Dry matter consumed)

$= C \times M$

$= 0.28 \times 20$

$\therefore \quad V_b = 5.6 \text{ m}^3/\text{day}$

Power availability from the digester.

We have,

$P = \eta H_m F_m V_b$

$= 0.65 \times 28 \times 0.7 \times 5.6$

$= 71.344$ MJ/day

$= 19.817$ kwh/day

$\therefore \quad P = 825.708$ W

3.3 Combustion Characteristics Of Bio-Gas-Utilization For Cooking – I.C Engine Operation And Economic Aspects

Q43. What are the applications of biogas?

Answer :

Biogas is a versatile fuel. It is mainly used for cooking purpose to replace burning of firewood, agricultural residues and dung cakes. It is also burnt for lighting purpose to replace kerosene.

Indian designs of biogas plants being based on cattle dung, produce the fermented material in the form of slurry. It is commonly used to compost other organic residues in pits and the composed material is applied in the agricultural fields as manure. Many times the slurry is dried and then used as manure. Some of the farmers apply it in the same form also on a limited scale. The slurry is used in pisciculture also.

The biogas slurry gives better response to crops than other bulky organic manures. The economic viability of a biogas plant also depends upon the optimum use of biogas slurry.

Biogas can be used to operate both CI and SI engines. CI engines can run on dual fuel (biogas + diesel) and pilot injection of diesel is necessary for igniting the mixture of air and biogas inside the cylinder. However, the initial starting of diesel engine is done on pure diesel. Spark ignition engines can be operated on biogas after starting on petrol. Therefore, it is economical to use it for IC engines.

Q44. What are the combustion characteristics of biogas?

Answer :

Combustion Characteristics

1. It has higher calorific value at about 20 MJ/m³.
2. Biogas can be compressed and stored at about 115 atmospheric pressure.
3. Biogas is obtained by a process of anaerobic digestion.
4. Minimum ignition temperature is 290°C.
5. The moisture content is 10%-30%.
6. The combustion energy content is 4.5 MJ/kg to 7 MJ/kg of raw material.
7. Density of biogas is 150 kg/m³.

Q45. Explain biogas utilization for cooking.

Answer :

Biogas produced by anaerobic fermentation of organic wastes consists of 55% – 65% of methane, 30% – 40% of carbon dioxide and some traces of other gases is a clean but a slow burning gas. It has a calorific value between 2100 kJ/kg and 23100 kJ/kg. It is utilized in cooking by replacing the burning of firewood, agricultural residues and dung cakes. It is one of the most economical way used for cooking. It eliminates the process of preheating which is a necessary step when cooking on biomass.

Biogas is used through conventional gas burners for cooking. A nozzle having a hole of 0.5 mm diameter is connected to the stove and the other end is connected to the hose which has gas supply from the digester. When biogas enters the stove, it sprays out from the nozzle at a very high velocity. During this, the air around the biogas becomes a low pressure area and therefore from the air inlets the air is passed into the mixing chamber. The air gets mixed with the biogas approximately in the ratio of 1 : 10. This mixture from the chamber then rushes to the outlet of the fire sieve plate where combustion is carried out. The pressure and brightness of stove depends on biogas pressure. In this way, the biogas through burners is utilized for cooking purpose.

Q46. What are the advantages and disadvantages of biofuels?

Answer :

Biofuels

The term biofuels is a contraction of the term bio-organic fuel and refers to the fuels made from living organisms or their metabolic byproducts. It is considered as a renewable source of energy because their sources can be grown again. Some of the examples of biofuel are biodiesel, bio-alcohol, ethanol, biogas, oil made from corn, sugarcane, soybeans, algae, vegetable oils and manure.

Advantages

The advantages of using biofuels are as mentioned below,

1. Biofuels are less expensive than gasoline and other fossil fuels.
2. They can be manufactured from recycled waste like manure, crop waste, etc.
3. Unlike fossil fuels, biofuels are renewable sources of energy as new crops can be grown and the waste material can be collected.
4. They do not harm the environment as they emit less particulate pollution.
5. Reduced dependence on foreign countries for oil import.
6. Biofuel production boosts a country's economy. It creates new job opportunities in biofuel manufacturing plants as well as in the production of biofuel crops.
7. Biofuels are considered as "carbon neutral" because the amount of carbondioxide released during combustion of biofuels is equal to the amount absorbed by the plants from the atmosphere. Also, it has been stated that, the use of biofuels reduce the carbon emissions by about 50% – 60%.

Disadvantages

The drawbacks of these energy sources are,

1. Biofuels are more expensive than traditional fuels.
2. Low energy output and power when compared to traditional fuels.
3. The natural habitats may have to be destroyed to produce biofuel crops.
4. Consumption of land to produce biofuel crops leads to less land availability for growing food. This may result in starvation in some parts of the world and increase possibility of rise in food prices.

Q47. What is biodiesel? How it is extracted?

Answer :

Biodiesel

The liquid fuel extracted from oil seeds (non-edible) that are grown on uncultivated or barren lands is known as Biodiesel. Some of the examples of these oil seeds are Karanja, Jatropha etc. In few countries of European Union and USA, the biodiesel is extracted from edible oil seeds like peanuts, soyabean, cotton seed, sunflower seeds etc. The first engine that runs on biodiesel was developed by Dr. Rudolf Diesel.

Biodiesel is a renewable fuel and is a best alternative fuel for diesel engines. It has no sulphur contents and produces less emissions.

The biodiesel directly extracted from seeds cannot be used to run engine as its viscosity will be 20 times greater than that of conventional diesel. This leads to problems like,

1. Serious lubrication
2. Contamination of oil
3. Choking troubles of injector.

In order to avoid this, the oil undergoes some process like trans-esterification. In this process, methyl or ethyl esters are formed by treating the raw oils from seeds with alcohol. The resulted mono-esters (methyl or ethyl) will have low viscosity, high octane number and more heating value. Thus the resulted esters are known as biodiesel.

Biodiesel Extraction from Jatropha

The Jatropha seeds are sent to the oil press where oil is derived from the seeds. This oil is treated with some alcohol (methanol) which gives three methyl ester and one glycerol molecules. The reaction is accelerated by using catalysts like alkalis (NaOH or KOH). The ratios of amount of Jatropha oil, methanol and catalyst in the reaction are 1000 : 400 : 10. When the reaction is completed, glycerol from the oil is separated and methyl ester is obtained. This methyl ester is the required 'biodiesel'.

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Q48. Explain about IC engine operation using bio-gas.

Answer : July-10, (R15), Q7(a)

IC Engine Working on Biogas

Compressed Ignition (CI) internal combustion engine can be operated using biogas by incorporating few modifications in it.

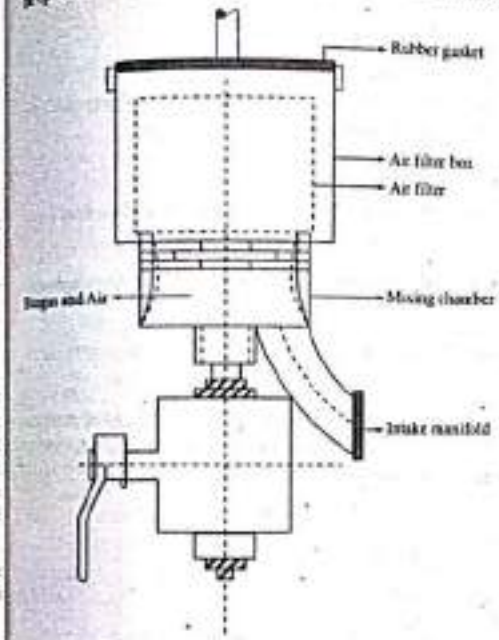

Figure: Air Filter Box and Mixing Chamber

In Compression Ignition (C.I) engines working on biogas, a mixing chamber is provided below the air cleaner with capacity equal to the engine displacement volume. In the mixing chamber, biogas is mixed with air which is then passed into the cylinder. Running the engine initially with biogas improves the engine speed.

Advantages of Operating CI Engine on Biogas

(i) Biogas is capable of substituting other engine fuels such as diesel, petrol etc.,

(ii) Biogas can substitute about 100% of petrol and 80% of diesel.

(iii) CI engines operated on biogas possess high efficiency.

(iv) Engine performance can be improved by reducing amount of CO_2 in biogas.

(v) Dual fuel (biogas + diesel) operated CI engines can give 31°-33° injection timing prior to TDC, which represents a better performance.

(vi) Usage of biogas is economical.

Q49. Explain the S.I engine operation using bio-gas.

Answer : May-11, (R09), Q5(c)

Operation of S.I Engine Based on Bio-gas

Spark Ignition (S.I) and Compression Ignition (C.I) engines can be operated using biogas by making few modifications to it. SI engines can be operated on biogas, but the starting of engine is carried out by petrol. The amount of gas required mainly depends upon the content of methane in the gas. The biogas possess higher octane number than petrol thus, producing excellent anti knock properties. It is safer than petrol as it has high auto-ignition temperature than petrol.

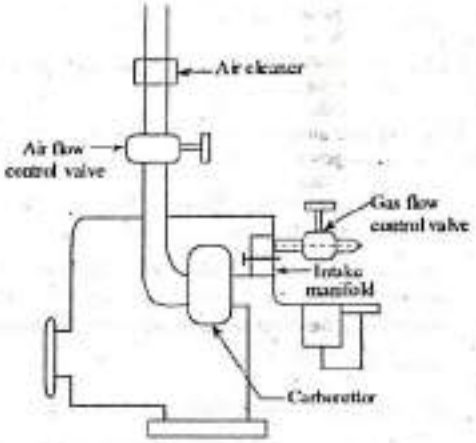

Figure: Modifications of S.I Engine of Bio-gas

Modifications required for the operation of engine with biogas includes providing the entry of biogas, throttling of intake air and advancing the ignition timing. The biogas from the fuel tank is supplied to the intake manifold passing through a carburetor. The air is filtered in an air cleaner before passing through the air control valve. This valve regulates the quantity of air to be flow into the carburetor. The air and biogas are throttled in the carburetor and supplied to the combustion chamber through a gas flow control valve. A typical S.I engine with modifications for biogas is shown in the above figure.

3.4 Economic Aspects

Q50. What are the various biomass energy programmes in India?

Answer :

Biomass Energy Programme in India

As a result of rapid urbanization and industrialization in India, some million tonnes of solid and industrial waste is released every year. This can be recovered by generating power from it.

By the end of January 2009, the various biomass resources that are converted to useful power and the details are listed below.

S.No.	Biomass Resources	Expected Power (MW)	Obtained Power (MW)
1.	Wood	52000	683
2.	Conversion of waste-to-energy		
	(a) Grid interactive	5000	34.95
	(b) Distributed	50000	11.03
3.	Gasifiers	-	87
4.	Baggasse	5000	1034
5.	Biogas plants (family type)	120×10^7	39.8×10^7

Number of projects installed in industries like oil-extraction, starch, paper mills, food processing etc., are thirty nine and their potential is 59 WM. Under installation projects are about eight in the country.

Examples

(i) Conversion plant in Lucknow, produces a power of 5 MW and 75 tonnes of biofertilizers utilizing Municipal Solid Waste (MSW) in the city.

(ii) In Tamil Nadu, a plant is located at Salem which utilises the waste water from a starch industry to produce high-rate bio-methane.

(iii) In Telangana, at Al-Kabeer of Medak district, a plant is located which utilises the waste from slaughterhouse to produce biomethane.

There are plants which utilizes the agricultural wastes. The power estimated from agricultural waste is 16881 MW, of which 605.80 MW is derived. The estimated potential from bagasse-based cogeneration plants is 5000 MW and only 710.63 MW is derived till now. The potential derived from non-bagasse plants is 95 MW.

Examples

(i) A grid-connected plant located at Chattisgarh, has a capacity of 6 MW, which uses rice husk.

(ii) A bagasse-based plant located at Tamil Nadu has a capacity of 40 MW.

The total potential of biogasifiers in India is 86.53 MW.

Example: A biogasifier of capacity 500 kW is located at Chotmollakhali island, West Bengal.

The plants that uses organic wastes and cattle waste established in the country are as follows.

(i) 39.40 lakh plants of family size which uses agro/cow waste.

(ii) 3902 plants of community/institutional based are located in different areas of India.

Q51. What is meant by energy plantation? What are its advantages and limitations?

Answer : [April-18, (EEE), (R13), Q7(b) | Model Paper, Q7(b)]

Energy Plantation

Energy plantation refers to the growing of special type of trees and shrubs that are to be harvested in a short period of time for the purpose of fuel. They are selected and harvested in such a way that, they produce a considerable amounts of fuel continuously around the year which can be used as an alternative fuel. The major sources of energy plantation includes availability of water, land and good plant management. Regular farm crops are not suitable for energy plantations as they do not supply the fuel throughout the year. The most suitable plants for energy plantations are those whose growth is very slow but the yield obtained is very high.

The total yield obtained from an energy plantation may be about 10 to 20 tonnes/acre/year. The land area may be ranging from 125 to 500 m^2.

The most common species used for energy plantation are Acavia Auriculiformis, Eucalyptus Camaldulensin, Casuarina Equisilifolia, Leucaena Lencocephala, Albizia Lebbek, etc.

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Advantages of Energy Plantations

1. Cost of fuel obtained is less than that of fossil fuels under optimised conditions.
2. No release of SO_2 on combustion of fuel.
3. No losses of storage.
4. Leftover ash after combustion, can be used as manure.
5. CO_2 released by the combustion of fossil fuels is consumed by the biomass which eliminates environmental pollution.
6. They balance the ecological system by converting semi-barren lands to green belt.

Limitations of Energy Plantation

1. This may cause disturbances in local bio-diversity.
2. Usage of fuel in urban area may affect the livelihood of rural areas and also disturb the environmental stability.
3. In order to produce plantation over large area, huge amounts of fertilizers, pesticides etc are used which causes pollution.
4. Requires more land, water and high maintenance.

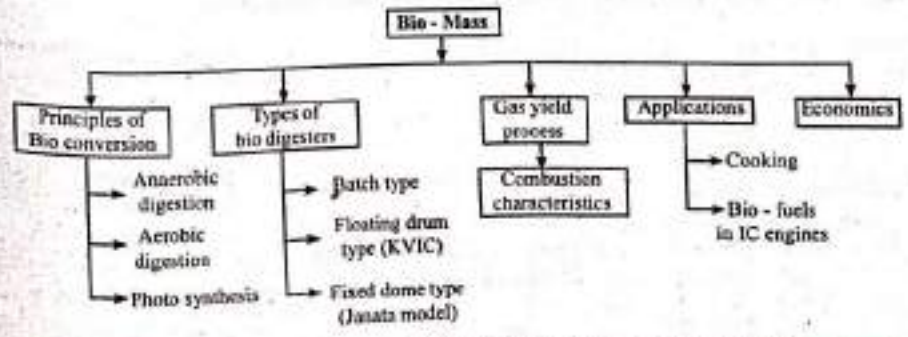
Q52. Why are biogas plants not much successful in India?

Answer : [May-15, (R09), Q5(a)]

Biogas plants are not much successful in India, due to the following reasons:

1. Methanogenic bacteria is responsible for the formation of biogas and they are very reactive and sensible to temperatures. Due to the low temperatures in winter, the formation activity is reduced, which results in low production rate of the biogas.
2. The main reason is due to the lack of knowledge and proper training on the biogas plant. Due to unskilled workers, the operation of plant becomes less effective.
3. The process consumes more time, as it includes many steps like dung collection, mixing water, waste disposal, etc.
4. Fertilisers like urea, when added in excess amount, to increase the production of gas, results in toxicity or undesired behaviour of ammonia or nitrogen. This leads to low production rates.
5. There is a lot of difficulty involved in clearing and recharging the complete tank of the plant, which should be performed for every 3 to 4 years.
6. Labour required is high, in order to handle the oil drums of about 200 litres capacity.
7. The biogas digester is not suitable for every climatic condition.
8. People in rural areas mostly use wood as fuel, which is available in abundance. Hence, biogas is not significant in such areas.
9. And, other problems are lack of awareness about advantages of biogas, component, availability, lack of co-operation with the government, etc.

MEMORY MAP



FREQUENTLY ASKED QUESTIONS AND IMPORTANT QUESTIONS

Q1. Compare and contrast the biomass and biogas. (2 TIMES)

Ans: Refer Q10. [May-17, (ME), (R13), Q7(a) | May-15, (R09), Q5(a)]

Q2. Discuss what are the biomass resources available for production of biomass energy. (2 TIMES)

Ans: Refer Q17. [April-14, (R05), Q5(a) | Sep-23, (R16), Q7(a)]

Q3. Explain with the schematic diagram the working of anaerobic digestion showing input material and effluents. (2 TIMES)

Ans: Refer Q26. [June-18, (R13), Q6(a) | May-13, (R09), Q5(a)]

Q4. What is anaerobic digestion?

Ans: Refer Q4. Important Question

Q5. List out the different types of biogas plants.

Ans: Refer Q11. Important Question

Q6. Discuss with sketch the working of a fixed dome biogas plant.

Ans: Refer Q30. Important Question

Q7. Compare the floating drum and fixed dome type biogas plants.

Ans: Refer Q34. Important Question

Q8. Classify biogas plants and discuss the parameters that affect the performance of biogas digester.

Ans: Refer Q41. Important Question

Q9. Explain about IC engine operation using bio-gas.

Ans: Refer Q48. Important Question

Q10. Explain the process of power generation from urban waste using incineration plant with a neat sketch.

Ans: Refer Q25. Important Question

Q11. Write short notes on biogas.

Ans: Refer Q37. Important Question

Q12. What is meant by energy plantation? What are its advantages and limitations?

Ans: Refer Q51. Important Question

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UNIT 4

GEOTHERMAL ENERGY AND OCEAN ENERGY

Syllabus

Geothermal Energy: Resources, Types of Wells, Methods of harnessing the energy, Potential in India.

Ocean Energy : OTEC, Principles, Utilization, Setting of OTEC plants, Thermodynamic cycles. Tidal and W Energy: Potential and conversion techniques, Mini-hydel power plants and their economics.

LEARNING OBJECTIVES

On completion this unit, the student shall be able to understand the following concepts,

- Resources of Geothermal energy
- Types of wells
- Methods of harnessing the Geothermal energy
- Potential of Geothermal energy in India.
- Ocean thermal energy conversion
- Tidal energy and wave energy
- Mini-hydel power plants

INTRODUCTION

Geothermal energy is the heat transported from the interior of the earth. It is recovep in some form such as steam or hot water. The earth is said to have been created as a mass of liquid and gases to 10% of which was steam. As the fluid cooled, by losing the heat at surface, an outer solid crust formed are steam condensed to form oceans and lakes in depressions of that crust.

Ocean waves are created by the interaction of winds with the surface of the sea. It can both kinetic energy and potential energy. The energy of the wave depends on the wind speed, the distance on hich it interacts with the water and its duration. The wave motion is horizontal and motion of water is primarily vol. In this, floats are used to convert water motion into mechanical power. A large float is driven up and down biter within stationary guides. This reciprocating motion is converted to rotary motion and then to electrical power

POINTS TO REMEMBER

- **Geothermal Energy:** It is the heat derived from interior of the earth. It can be obtained in the form of steam or hot water.
- Geothermal resources are classified as,
  - i. Hydrothermal systems
    - a. Vapour-dominated system
    - b. Liquid-dominated system
    - c. Hot-water fields
  - ii. Geo-pressured systems
  - iii. Petro-thermal systems
  - iv. Magma resources
- The Geothermal energy are applied in,
  - i. Electric generation
  - ii. Industrial process applications
  - iii. Agriculture /Aquaculture
  - iv. Direct Heating
- **OTEC system:** OTEC thermal energy conversion system work on the basis of thermal gradient principle. It states that if a heat source is available at higher temperature and a heat sink at lower temperature, then it is possible to utilise the temperature difference to operate a machine or prime mover such as turbine, which can convert a part of heat taken from the source into mechanical energy and hence into electrical energy by using a generator. The remaining heat is discharged to the sink at lower temperature.
- **Tidal energy:** It refers the hydro energy in ocean tides. Tides occur due to the gravitational attractive forces from the sun and the moon.
- **Wave energy:** It refers the waves of water from ocean to the shore. Waves occur due to the rotation of the earth and the winds over ocean sea.

PART-A SHORT QUESTIONS WITH SOLUTIONS

Q1. Comment on the origin of geothermal energy.

June-18, (R13), Q1(g)

Define a geothermal source.

Answer :

Geothermal energy is heat derived from interior of the earth. It can be obtained in the form of steam or hot water.

Along the depth of the earth's surface, there exists different temperatures. The temperature increases with the increase in depth. Also, there are some real hot spots below the earth's surface, which possess high temperatures. Thus, when water comes in contact with these temperature regions, it gets converted into steam.

Q2. What are the different types of geothermal resources?

Answer :

[May-19, (R15), Q1(g) | Model Paper, Q1(d)]

Geothermal resources can be classified as,

1. Hydrothermal resources
   - (i) Vapour-dominated fields
   - (ii) Liquid-dominated fields
   - (iii) Hot-water field
2. Geo-pressurised resources
3. Petro-thermal or hot rocks
4. Magma resources.

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Q3. Write about environmental impact of geothermal resources.

Answer :

Environmental impact of geothermal resources.

1. It pollutes soil air and affects the aquatic life of organisms.
2. It uses very large area and results in soil erosion.
3. The drilling operation performed during geothermal extraction causes noise pollution.
4. Harmful gases like O_2, SO_2, H_2S are released into atmosphere. This causes air pollution and leads to health issues.
5. The extraction of geothermal energy also leads to drying of hot springs.

Q4. What is hyper-thermal field in geothermal energy and explain?

Answer :

April-18, (EEE), (R13), Q1(g)

It is one of geothermal fields which produces pressurised water at a temperature above 100°C or pressurised steam in dry saturated or superheated form.

Hyper-thermal Field

(a) Wet Field

They produce large amount of pressurized water at a temperature above 100°C and small amounts is splashed into steam at the surface.

(b) Dry Fields

They produce dry saturated steam or superheated steam at the surface. The pressure of the steam is above atmospheric pressure.

Q5. Draw the hydrothermal convective region.

Answer :

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

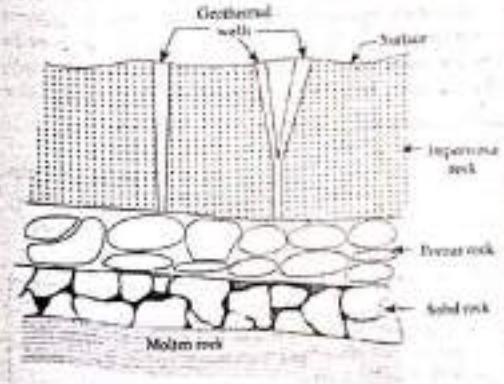

Figure: Hydrothermal Convective Region

Q6. What are various methods adopted to drill geothermal wells?

Answer :

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

Various methods adopting to drill geothermal wells are,

1. Cable-tool percussion drilling
2. Radial jet drilling
3. Hydraulic percussion drilling
4. Bucket auger method
5. Hydraulic rotary drilling
6. Air rotary drilling
7. Reverse circulation drilling.

Q7. List various types of geothermal wells.

Answer :

Various geothermal wells are,

1. Self-discharging well
2. Pumped wells
3. Reinjection wells
4. Monitoring wells
5. Other types
   - (i) Petroleum wells
   - (ii) Ground-water wells
   - (iii) Coal bed methane wells (CBM)
   - (iv) Waste water disposal wells

Q8. What is the current status of geothermal energy in India?

Answer :

[June-18, (R13), Q8(a) | April-14, (R09), Q7(b)]

There is a wide scope to develop geothermal power in India, but still development of geothermal field is in initial stage. In India, about 350 thermal areas are found by GSI (Geological Survey of India). They determined that about 113 spring areas has geothermal energy and can be utilised. Among these, 46 systems are of high temperature type, which could generate 1858 MW for a period of 30 years. The most important plant is located at Puga Valley in Ladakh (Jammu and Kashmir) in Himalayas. The other places with geothermal resources are along Narmada-Son lineament (NSL) at Anhoni-Samoni, Chattisgarh and Madyapradesh, Manuguru (Telangana), Barkeshwar (West Bengal) etc.

Q9. What is the difference between fissures and fumaroles in geothermal energy?

Answer : April-18, (ME), (R13), Q1(a)

Differences between Fissures and Fumaroles

	Fissures		Fumaroles
1.	These are a type of volcanic vents that are linear and from which lava and gases explode out.	1.	Fumaroles are the small openings in the earth's crust surrounding a volcano.
2.	They are formed on ground with long lengths and less width.	2.	These forms a white cloud of different sizes.
3.	They eject lava.	3.	These do not eject lava, but emits gases and water vapour.
4.	They appear as fractures on the ground	4.	They appear as white layers around volcanic openings.

Q10. List the advantages of geothermal energy.

Answer : July-19, (R13), Q1(k)

Advantages of Geothermal Energy

1. It is a renewable source of energy.
2. The cost of the energy is less.
3. High energy content can be obtained.
4. The annual load factor of geothermal power plants is very high i.e., about 85 % to 90 %.
5. It causes less pollution.
6. Unlike other energies (solar, wind), it is independent of weather conditions.
7. Additional storage facility is not required. It can be used in wide range of applications.

Q11. Explain the principle of energy extraction from OTEC system. May-19, (R15), Q1(k)

OR

What is the principle of OTEC?

Answer : April-18, (ME), (R13), Q1(j)

Principle of Ocean Thermal Energy Conversion

A sufficient amount of heat from the solar energy is collected by the upper surface of the ocean, which acts as a collector. Therefore, the upper layer acts as hot temperature source and the inner deep layer acts as low temperature source. Hence, there exists a thermal energy gradient or thermal gradient in the ocean. This thermal energy gradient can be used to generate electric power, by utilising the high temperature water for evaporation of fluid, which in turn drives the turbine of power plant, and the low temperature water is used for condensation of the turbine exhaust. Thus, the cycle continues and power is generated.

Q12. What is meant by Bio fouling?

Answer : May-17, (ME), (R13), Q1(l)

Bio fouling is the deposition and growth of micro organisms on evaporator and condenser metal surfaces of an OTEC plant, creating thermal resistance for heat transfer. It inhibits heat transfer during the heat exchanging process. The thermal resistance of the fouling film is called the fouling factor. Some provisions must be taken to suppress the formulation of fouling layers on the surfaces of OTEC heat exchangers and to remove the film. These can be accomplished by cleaning the heat exchanger surfaces through mechanical, chemical or other means. Bio-fouling can also be reduced by increasing the flow rate of water, but the increase in flow rate may cause erosion.

Q13. Compare and contrast different types of tides.

Answer : June-18, (R13), Q1(f)

Generally, the tides are classified into two types. They are,

1. Neap tides
2. Spring tides.

	Neap Tide		Spring Tide
1.	Neap tide occurs when solar and lunar pulls act at perpendicular to each other in the first and third quarters of a lunar month, and causes low tides or neap tides.	1.	Spring tide occurs when solar and lunar pulls come in line at 'New moon' and 'Full moon' and causes greater flow and ebb.
2.	Neap tide has the minimum tidal range of its lunar moth.	2.	Spring tide has the maximum tidal range of its lunar month.

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Q14. What is tidal energy? Classify different tidal plants.

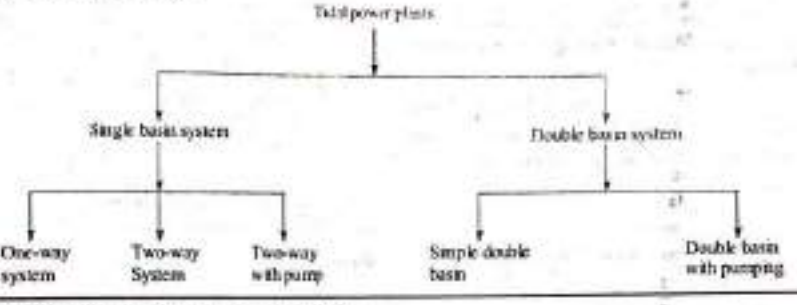
Answer :

Tidal Energy

Tide is a periodic rise and fall of water level of sea due to the attraction of sea water caused by the moon. The energy obtained by these tides to produce electrical power is known as tidal energy or tidal power.

When the water level is above the mean water level of sea, it is called as full tide or flood tide. When the water level is below the mean water level of sea, it is called as Ebb tide. Usually, a dam is constructed with a basin separated from the sea to maintain a difference in the water level. During high tide, the basin is filled with water which is then passed into the sea through turbine and thereby, producing the power.

Classification of Tidal Power Plants



Q15. What are the limitations of tidal power plant?

Answer : [Nov./Dec.-15, (R13), G8 | Model Paper, Q1(i)]

The following are the limitations of tidal power plant.

1. High initial cost of the plant.
2. The machinery may get corroded because of the effect of sea water.
3. The efficiency of tidal plant is effected due to variation in tidal range.
4. The cost of power transmission is more as tidal power plants are located far from load centres.

Q16. What are the site requirements for power generation from tides?

Answer :

Utilization of a tidal energy requires a barrage or dam that is constructed across a narrow inlet to an estuary or bay. Thus, forming an enclosure in which ocean water is filled. Electricity is generated by allowing water to flow from basin to open ocean through turbine and also, the basin is being filled from the ocean during rising tides. The amount of electrical energy generated depends on the product of the tidal range (Difference between consecutive high tide and low tide water level) and the mass of water flowing through the turbine. The volume is equal to the range multiplied by the area of the water in the basin. Hence, the electrical energy is proportional to the square of the range and the area of the enclosed basin.

From the above discussion, it can be concluded that more electricity is generated with a large tidal range. Hence, the site for the utilization of tidal energy should have a large tidal range and should permit enclosure of large areas with reasonably short dams or other barrages.

Q17. Discuss briefly the economic aspects of tidal energy conversion.

Answer :

The cost of tidal energy system/scheme includes following various costs.

1. Cost of barrages.
2. Cost of land of basins and development of basins.
3. Cost of power plant.

Therefore, the capital cost per kWh of tidal energy is very high. However, the maintenance and running costs are low.

The mini hydroprojects are more advantageous than tidal power plants. The tidal plants are considered to be economical when the conventional fuel costs become more or all conventional energy reserves are depleted.

Q18. What is the fundamental principle in energy conversion from ocean waves?

Answer :

Ocean waves are created by the interaction of winds with the surface of the sea. It contains both kinetic energy and potential energy. The energy of the wave depends on the wind speed, the distance over which it interacts with the water and its duration. The wave motion is horizontal and motion of water is primarily vertical. In this, floats are used to convert water motion into mechanical power. A large float is driven up and down by water within stationary guides. This reciprocating motion is converted to rotary motion and then to electrical power.

Q19. Discuss the wave energy conversion machines.

Answer :

May-17, (EEE), (R11), Q1(g)

The different types of wave energy conversions are classified according to the following parameters such as,

(a) According to Location

(i) Shore line machines

(ii) Deep water (or) off shore machines

(b) According to Position

(i) Floating wave power machine

(ii) Submerged power machine

(iii) Partially submerged machines

(c) According to the Actuating Motion

(i) Heaving type

(ii) Surge type

(iii) Oscillating water column etc.

Q20. Define small, mini and micro hydro power.

Answer :

Depending on the capacity, the hydro power systems are classified as follows.

1. Small Hydro Power System

The hydro power system whose electricity generating capacity ranges from 1MW to 20 MW, is called as small hydro power system.

2. Mini Hydro Power System

The hydro power system whose electricity generating capacity ranges from 100 kW to 1 MW is called as Mini Hydro power system. It a subtype of small hydro power system.

3. Micro Hydro Power System

The hydro power system whose capacity ranges from 5 kW to 100 kW is called as Micro Hydro Power. This hydro power does not have a dam or reservoir. It is also a subtype of small hydro power system. These definitions are with respect to India and they may differ from country to country.

Q21. Classify the small hydro power (SHP) stations.

Answer :

According to the central electricity authority (CEA) and ministry of new and renewable energy (MNRE), small hydropower stations are classified as follows.

1. Based on the capacity range,

	Type of SHP	Capacity Range
1.	Micro	Upto 100 kW
2.	Mini	101 kW to 1000 kW
3.	Small	1 mW to 25 mW

2. Based on available head.

	Type of SHP	Head Range
1.	Ultra low head	Below 3m
2.	Low heat	Above 3m and upto 40m
3.	Medium or high head	Above 40m

Q22. Give the classification of water turbines.

Answer :

The water turbines are mainly classified as follows,

1. Impulse Turbines (High Head Turbine)

The impulse turbines are further classified into following types.

	Types	Head Range
1.	Pelton wheel	60 m to 700 m
2.	Turgo turbine	30m to 210 m
3.	Ossberger cross flow	1m to 200 m

2. Reaction Turbines

(i) Propeller Turbine :

The reaction turbines are further classified into following types.

	Types	Head Range
1.	Axial flow turbines	Low head
2.	Kaplan turbine	25m to 40m
3.	Tube turbine	2m to 15m
4.	Bulb turbine	1.5m to 25m
5.	Straflo turbine	2m to 25m

(ii) Francis Turbine :

It is a medium head mixed flow (radial and axial) turbine.

The head varies from 40 m to 300 m.

Q23. Draw Claude cycle of OTEC system.

Answer :

April-18, (EEE), (R15), Q10(f)

For answer refer Unit-IV, Q51, Topic: Only Figure (1)

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Q24. Find the quantity of water to be pumped to OTEC plant working with surface water at 27°C and with cold water at 8°C at a depth of 600 m from the surface to obtain 1.0 MW of thermal energy. Assume the density of ocean water as 1010 kg/m³ and the specific heat of water as 4200 J/kg K.

Answer :

Given that,

Output power developed, $P_o = 1 \times 10^3$ kW

Surface water temperature, $T = 27°C$

Temperature difference, $\Delta T = 19°C$

Density of water, $\rho = 1010$ kg/m³

Specific heat of water, $C = 4.2$ kJ/kg K

Efficiencies of turbine and generator are assumed as,

$$\eta_T = 0.75$$

$$\eta_G = 0.96$$

Actual power to be developed,

$$P = \frac{P_o}{\eta_T \times \eta_G}$$

$$P = \frac{1 \times 10^3}{0.75 \times 0.96}$$

$$\therefore P = 1.38 \times 10^3 \text{ kW}$$

But, $P = \rho C Q \Delta T$

$$1.38 \times 10^3 = 1010 \times 4.2 \times Q \times 19$$

$$Q = \frac{1.38 \times 10^3}{1010 \times 4.2 \times 19}$$

$\therefore$ Quantity of water to be pumped, $Q = 0.017$ m³/sec

PART-B ESSAY QUESTIONS WITH SOLUTIONS

4.1 Geothermal Energy

4.1.1 Resources

Q25. What is meant by geothermal energy?

Answer :

Geothermal Energy

Geothermal energy is heat transported from the interior of the earth. It is recoverable in some form such as steam or hot water.

The earth is said to have been created as a mass of liquid and gases, 5% to 10% of which was steam. As the fluid cooled, by losing heat at the surface, an outer solid crust formed and the steam condensed to form oceans and lakes in depressions of that crust. The crust now averages about 32 km in thickness. Below that crust, the molten mass called magma is still in the process of cooling.

Geothermal steam is of two kinds,

1. **Magmatic Steam :** Originating from the magma itself.
2. **Meteoritic Steam :** Obtained from ground water heated by the magma. It is the largest source of geothermal steam.

Factors that Decide the Usage of Geothermal Energy in Power Generation

1. More flexible to use
2. Low cost
3. High energy content
4. High capacity factor (it is the ratio of actual energy generated to the product of capacity and time).
5. High energy density
6. Highly responsive and easily controllable

Q26. What are the advantages and disadvantages of geothermal energy over other energy forms?

Answer :

Advantages of Geothermal Energy

For answer refer Unit-IV, Q10.

Disadvantages of Geothermal Energy

1. It has less overall efficiency in power production, that is about 15%, whereas the fossil fuel plants possess an efficiency of 35% to 40%.
2. It may cause surface instability, due to the continuous extraction of energy.
3. Harmful gases are released during extraction of energy, which causes air pollution.
4. The extraction of energy creates noise pollution due to drilling operation.
5. The availability of geothermal resources are very less i.e., only in certain places. Therefore, power plants are installed only in few places.

Q27. How is geothermal energy generated inside the earth crust? In India where is geothermal energy available?

Answer :

The geothermal field consists of magma, rocks, reservoir, geysers, springs, fissures, wells etc., as shown in figure.

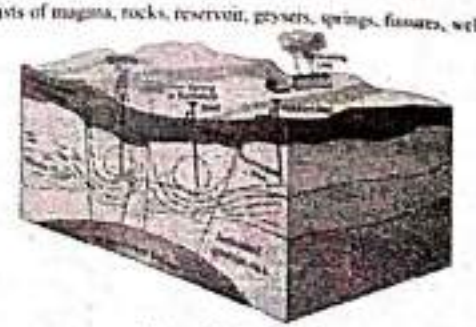

Figure: Geothermal Field

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The lower most portion of the field is "magma" i.e., hot molten rock. Above magma there are igneous rocks which were formed due to the solidification of magma. The water from the surface reaches to the underground through fissures and gets heated due to the high temperature of igneous rocks and converts into hot steam which moves upwards into a permeable reservoir. This hot water is protected by the hard layer of rock. There are vents inside the rocks which on moving to the surface of earth are termed as geysers and hot springs. The heated water is utilized for geothermal power plant by digging the wells into the underground geothermal field.

Geothermal Provinces of India

In India, there are 400 geothermal springs of medium and high enthalpy. Most of them are liquid dominated systems. Among them one or two consists of both liquid and gas dominated systems. All these systems are located in seven provinces in the country.

Geothermal Provinces

1. **The Himalayan Province :** It is one of the best provinces in India.
   Number of springs : 100 (approximately)
   Surface temperature : 90°C
   Discharge : greater than 190 tons/hour
2. **Cambay Province :** It is located in Gujarat and extended to some parts of Rajasthan. It is a part of Cambay basin.
   Number of discharge sites : greater than 15
   Surface temperature : 40°C - 90°C
   Reservoir temperature : more than 150°C
   Steam Discharge : 3000 m³/day
3. **West Coast Province :** It is located in Maharashtra.
   Number of hot water springs : 60
   Surface temperature : 40°C - 72°C
   Sub surface temperature : 110°C - 150°C
4. **Sonata Province :** It is the acronym of Son - Narmada - Tapti. This province extends from Cambay (west) to Bakreswar (east). The famous sites of this province are Tattapani, Salbardi, Surajkund.
   Surface temperature - 30°C - 93°C (thermal springs)
   Surface temperature - 24°C - 25°C (cold spring)
   Reservoir temperature - 132°C - 265°C
5. **Sohana Province :** It is located in Gurgaon district of Haryana.
   Surface temperature - 24°C - 46°C
   Reservoir temperature - 100°C
6. **Godavari Province :** It is located in Andhra Pradesh
   Number of thermal discharges : 13
   Surface temperature - 50°C - 60°C
   Reservoir temperature - 175°C - 215°C
7. **The Mahanadi Province :**
   Number of geothermal springs : 8
   Surface temperature - 96°C
   Reservoir temperature - 180°C

Q28. Explain the nature of geothermal fields.

Answer :

Geothermal field may be classified based on the following parameters.

1. **Temperature Gradient**
   (i) **Non-thermal Areas**
   The areas where temperature gradient is 10°C to 40°C/km depth.
   (ii) **Semi Thermal Areas**
   The areas where temperature gradient is 70°C per km depth.
   (iii) **Hyper-thermal Areas**
   The areas where temperature gradient is very high compared to non-thermal areas.

2. **Pressure and Temperature**

(i) **Hyper-thermal Fields**

(a) **Wet Field**

They produce large amount of pressurized water at a temperature above 100°C and when pressure is released into steam drive turbine.

(b) **Dry Fields**

They produce dry saturated steam or superheated steam at the surface. The pressure of the steam is above atmospheric pressure.

(ii) **Semi-thermal Field**

The temperature of hot water in this field is above 100°C.

Q29. Discuss in detail about various methods to harness geothermal energy. May-13, (R09), Q6(a)

OR

Explain various methods of harnessing the energy. May-11, (R09), Q6(b)

OR

Classify various geothermal resources. May-13, (R09), Q6(a)

OR

Describe various energy extraction technologies used with hydrothermal resources.

Answer : [June-15, (R13), Q6(b) | Model Paper, Q6(a)]

Geothermal resources are classified into four types. As per the resources, there is the method of extracting the energy.

Geothermal sources can be classified as

1. **Hydrothermal systems**
   - (i) Vapour-dominated system
   - (ii) Liquid-dominated system
   - (iii) Hot-water fields.
2. **Geo-pressurised systems**
3. **Petro-thermal systems**
4. **Magma resources**

1. **Hydrothermal Systems**

Due to the magma magma's heat, water on the surface of the magma gets heated. There can be vapour-dominated and liquid-dominated systems.

(i) **Vapour-dominated System**

In this type of system steam is generated as the water gets heated due to the heat of magma. This steam is used to produce power by Rankine cycle.

(ii) **Liquid-dominated System**

The water temperature in the reservoir is above 100°C, but water does not boil as it is under pressure. As the water comes to the surface, there will be pressure drop and rapid boiling of water takes place which "flashes" into a mixture of hot water and steam. This hot water can be utilized to generate electric power.

(iii) **Hot-water Fields**

It is similar to the liquid-dominated system.

2. **Geo-pressurised Systems**

Geo-pressurised system is hot water in which substantial amount of methane are dissolved. These are at about 150°C, under very high pressure trapped underground at about 2400 to 3100 m depth. Electricity is generated by the combustion of methane as well as heat from the trapped energy of water.

3. **Petro-thermal Systems**

When there is no availability of water at normal depths this is used. Though water is not available there will be hot rocks at normal depths. So the cold water is pumped into hot rocks by which water gets heated and should be get back out of the surface, thus electricity is produced. These temperatures of hot dry rocks can be called as petro-thermal energy.

4. **Magma Resources**

These consist of partially or completely molten rock with temperatures in excess of 650°C, which may be available at moderate depths. These have large geothermal energy content, but are restricted to few locations.

Q30. What are hydrothermal resources? Explain.

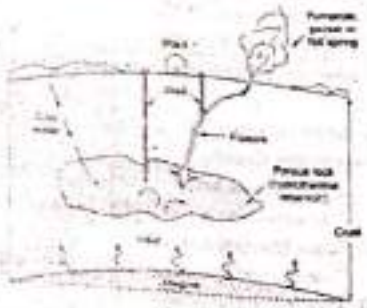
Answer :

Hydrothermal resources

These are the natural and commonly used sources of geothermal energy. The surface water enters into the earth crust and the deepest layers of 2 to 15 km. The water reaches a reservoir which is created by solid impervious rocks. When the water comes in contact with the hot rocks above the magma, it is heated by the heat generated from the magma upto a temperature of 150°C and to pressure also increases. The density of water is less compared to cold water. Therefore, the hot water rises up and escapes through the fissures and forms as hot springs (geysers) on the surface. In most cases, the layer of the impervious rocks restricts the flow of hot water. In such places, the hydrothermal energy is obtained by drilling wells.

Based on the output obtained, hydrothermal resources are classified into two types.

1. **Vapour Dominated Systems :** In this system, the energy is obtained in the form of steam with no or less water. The temperature ranges from 150°C - 250°C.
2. **Liquid Dominated Systems :** In this system, the energy obtained is a mixture of steam and hot water.



Figure

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Q31. Describe with a neat sketch the hot spring structure. May-13, (R09), Q6(a)

Answer :

Hot springs are the springs of water, which is heated geothermally to high temperatures. They produced through hot molten magma, crystalline rocks, permeable rocks and draining ground water.

The water which is deposited from the industries and due to rainfall, is drained through the gap and fractured rocks present on the earth's crust. This water which is percolated deeply, comes in contact with the permeable rocks and near such rocks. Later, the water passes through the 'impermeable rocks' which are laid below the permeable rocks and then conducts the hot magma. Hot magma which is a molten mass which is present at a depth of 5000 m at the earth's core, from the earth's crust. This hot magma transfers the heat to the percolated water by conduction. As a result, this hot water escapes out through the fractured rocks and comes out as springs.

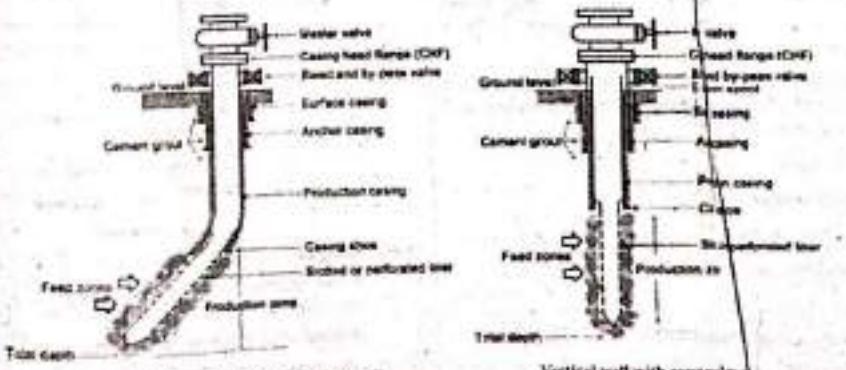
Figure: Hot Spring Structure

4.1.2 Types of wells

Q32. Explain self-discharging wells with neat sketches.

Answer :

Self-discharging wells are the most effective wells and generate high energy. The circulating pump and the boiler are repulsed by these wells. Most of the production wells, 2-phase and vapour dominated wells are self-charging. These wells have lower reservoir pressure. The wells which self discharge are changed into either monitoring wells, reinjection wells or even abandoned.



Deviated (S-shaped) with an expansion spool — Vertical well with expansion

Figure

These wells are dened based on the casing design. There are different types asings used in different sizes of wells (large, standard andall). They are,

1. Conductor casing
2. Anchor casing
3. Surface casing
4. Production casin

Different wellse drilled to various depths i.e., conventional wells areled upto 1000 to 2500m, Enhanced Geothermal System (E0wells are drilled to more than 3000m. The construction of a i/-ncharging well consists of various parts as shown in figu G the top of the wellhead assembly there is a service vals I runs the down-hole measurement tools.

Casing Head Flange(CF) : It is the valve which connects the master valve to theasing.

Single Skin Assembl: Ifhe wellhead assembly is connected to production casing, is tmed as single skin assembly.

Double Skin Assemly

If the wellheaassbly is connected to anchor casing through an expansionpostthen it is known as double skising assembly.

Expansion Spool : It makthe production casing to expand or contract thermally witl lessovement of wellhead assembly.

Permanent Thrust Fram

When the well cepls thermally in vertical direction, this frame supports the weld assembly in the axial direction.

Q33. Explain in detailsut pumped wells

Answer :

Pumped wells are thothermal wells which use pumps. The wells which cannot -discharge are made to function using down-hole pumps, anic Rankine Cycle power plants use these types of wells. Fot water systems wells are drilled to more than 600m and form water systems, wells are drilled to more than 2000m. Pud wells are also used for direct applications.

The down-hole pus can function at a temperature less than 240°C. The facwhich affect the selection and installation of these are,

1. Well design
2. Fluid chemistry
3. Reservoir pressure
4. Production flow ate
5. Permeability.

The down-holeumcare of two types. They are,

1. Submersible pmps' down-hole motor
2. Line shaft puns or'p drive pumps

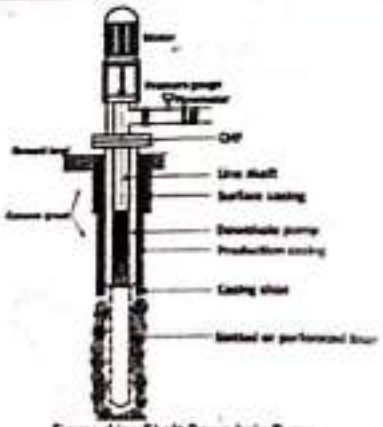


Figure :Line Shaft Down-hole Pump

The pump is generally placed within the cased part of the well to ensure that the pump does not collapse. Generally, the initial cost and maintenance of pumped wells are more. The life span of the pumps is also comparatively less.

Q34. What are airlifted wells? List its disadvantages.

Answer :

Airlifted wells are mostly used for small and medium rates domestic uses such as bathing, space heating, etc. In these wells, air from a compressor is blown into a shallow well. The air mixes with the hot water below the water level and reaches the earth's surface due to the gradual decrease of the mixed fluid.

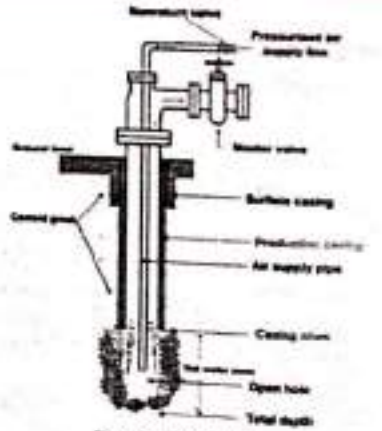


Figure : Airlifted well

Disadvantages

1. As air (oxygen) is blown into the well, it can cause corrosion.
2. Deposition of minerals on the parts.
3. Less power output, therefore they are not used in power generation.
4. Not suitable for large flow rates.

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Q35. Write a brief note on reinjection wells and monitoring wells.

Answer :

Reinjection Wells

Geothermal fluids are sent back into the reservoir after extracting the energy from them. This process is called reinjection and it has many advantages. It also protects the environment from further pollution. The wells used for such purposes are known as reinjection wells. Their design and drilling is similar to the production wells.

In order to avoid the risk of vertical reverse (vertical) flowing of the fluid, the process of reinjection should be done under gravity and with no pressure during the process.

Monitoring Wells

As the name represents these wells are used to measure and monitor the variation of various parameters such as temperature, pressure, water level, fluid chemistry, etc. They give a warning symbol of there is any reverse flow of hot fluid during the injection process. They are shallow wells of less than 100 m depth because depth of the well increases its cost.

The unused production and reinjection wells are converted into deep monitoring wells to observe the changes in the deep reservoirs. In some places, dedicated deep monitoring wells are drilled upto a depth of 400 m to 1500 m with similar casing of production wells. But, in order to decrease the cost, these deeper wells are made of small diameter.

The bubbler tube or the capillary tube is mostly used in deeper reservoirs because due to the high temperatures and harsh fluid chemistry, electronic devices cannot be used in such deeper sections. These are used to monitor the pressure at the reservoir and ensure if at the pump is not dried up.

Q36. List various other types of wells and explain any two of them.

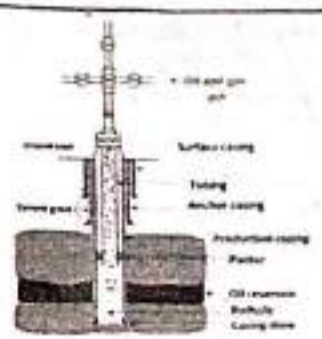
Answer :

Certain wells are drilled for a few purposes by industries and departments such as mining. They are,

1. Mining exploration wells
2. Petroleum wells
3. Coal bed methane wells
4. Waste water disposal wells
5. Groundwater wells.

Petroleum Wells

These wells are used to extract petroleum from the deep reservoirs. Based on the production targets, they can be either vertical or horizontal. These wells have relatively smaller diameters of 5.5 to 7 inches. They have limited output and less operating temperatures. Therefore, they are not used for production of geothermal energy. A permanent tubing or down hole pump is installed down the well. Some wells are also installed with petroleum down hole pumps and a shaft to drive them.



Figure

Ground-Water Wells

These are used for the extraction of water for domestic and industrial purposes. A well dug by the village people is also an example of ground-water well. It has concrete or stone lining and has a large diameter. Also, it is of less cost. In drill deeper wells, rotary drilling is employed. It depends on drilling conditions and depth of the well. Nonmetallic casings are widely used for such wells.

When excess water is available in the winter season, these wells are used for storing them so that they can be used in drought conditions. Slug test is conducted by sending the air of high pressure to airlift the water from the bore well. It is done before the pump installation.

Q37. What are CBM wells and waste-water disposal wells?

Answer :

Coal Bed Methane Wells (CBM)

These wells are used to extract the methane gas which occurs in coal naturally. In the middle stage of coal formation, coal acts as a source of gas and reservoir. CBM reservoirs are better and environment friendlyresources when compared to coal and oil. Their reservoirs are available within the coal range of sub-bituminous to low volatile bituminous. They are described based on the following factors.

1. High permeability
2. High reservoir pressure
3. High gas content
4. Large thickness of coal bed.

The down hole pumps are used in CBM wells for the following purposes.

1. Remove water from the coal
2. Decrease the reservoir pressure
3. To desorb the gas from the coal

Waste-water Disposal Wells

These wells are used to dispose of the waste fluid into the ground. These wells are mostly drilled by the industries. Sometimes water is also reinjected into the ground and it was first started in the year 1865 by a petroleum industry. The field operators are instructed to provide best designs for such wells to protect the environment as the waste waters consist of harmful chemicals such as boron, chloride and selenium.

4.1.3 Methods of Harnessing the Energy – Potential in India

Q38. How does harnessing of geothermal energy work? Explain.

Answer :

Harnessing of Geothermal Energy Work

Geothermal energy is harnessed from the earth's crust, where hot magma and water is present in the deeper regions. The heat of the magma is reaches the surface of the earth by convection process through the vents. This heat produced can be used directly in buildings or can be used to drive turbines to generate electricity.

Heat from the magma and water is brought onto the earth's surface in following two ways,

1. **From Natural Geysers**

   The heat from the magma converts the water in the underground reservoir into steam. This steam and hot water gets trapped in the space between the rocks present above the hot magma and escapes through the earth's surface in the form of fountains called geysers. The steam which is produced through these natural geysers is delivered to the turbines to produce electricity.

2. **By Drilling Pipes**

   It is the alternative method in which the pipes are inserted into the deeper regions of the earth. The steam which is trapped inside rocks is pumped out through these pipes with high pressure. This steam is used for driving turbines and generate electricity.

Q39. Discuss vapour dominated geothermal plant with a diagram.

[April-18, (ME), (R13), Q8(b) | Model Paper, Q8(b)]

OR

Differences between open-loop and closed-loop control systems.

Answer : **Nov./Dec.-17, (ME), (R13), Q8(b)**

Vapour Dominated System

These systems extracts dry steam of 200°C and pressure limited to 8 bar, i.e., similar to the steam used in turboelectric power plants. Hence, they are also known as dry steam fields. The cost of power generation is less, but adverse effects caused by corrosive gases and erosive material. There are only few vapour dominated systems in the world.

Working of Vapour Dominated Power Plant

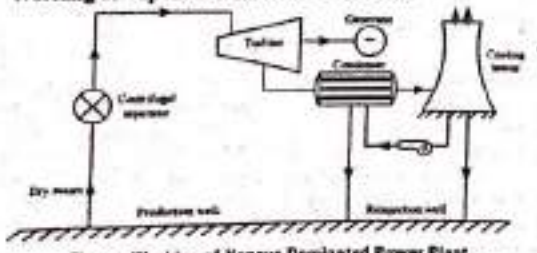


Figure: Working of Vapour Dominated Power Plant

It consists of a centrifugal separator, turbine, condenser, generator and a cooling tower.

During its working, dry steam is extracted from the reservoir and passed into the centrifugal separator through the production well. In centrifugal separator, the solid particles and impurities present in steam are removed. Then, this steam enters the turbine, where it expands over the turbine blades, to run the generator coupled to it. The exhaust steam from the turbine is supplied to the condenser, where the wet steam get condensed by means of cooling water. The excess water is again supplied into the reservoir through a injection well. The warm water leaving the condenser is supplied to the cooling tower, where it is cooled and directed back to the condenser.

Q40. Explain the principle and operation of a liquid dominated system with a neat sketch.

Answer :

Liquid-dominated Systems

In a liquid-dominated system, the temperature of the underground water is slightly higher than its boiling point temperature. But the liquid does not boil because of the under pressure in the reservoir. As the water reaches to the surface, there will be pressure drop and rapid boiling of water takes place which flashes into a mixture of hot water and steam. The mixture is made to pass through the cyclone separator where the water and steam is separated. The steam is made to pass through turbine which is attached to a generator for generating electricity. The water is made to pass through condenser and then again into the geothermal wells.

The liquid-dominated system is classified into following types. They are,

(a) The flash steam system

(b) The binary system

(c) The total flow system.

Flash System

The flash system consists of a flash chamber, turbine, generator, condenser, pump, etc., as shown in figure. There are three types of flash systems. They are,

(i) Single-flash system

(ii) Double-flash system

(iii) Multiple-flash system.

In these systems, the hot brine solution i.e., mixture of salt water and steam is made to pass over the flash chamber using throttling process. In flash chamber the low quality mixture of steam and water is separated and the high quality mixture is passed into the steam turbine. The steam turbine is connected with the generator, which results in the production of electricity. The remaining steam is made to pass through condensers and then into the geothermal wells through pump.

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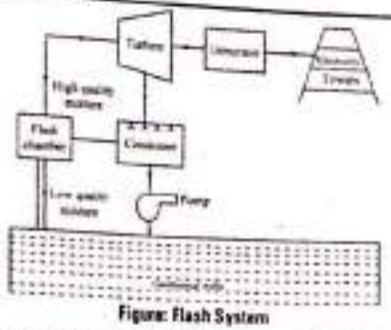

Figure: Flash System

Similarly, the process is carried on double and multiple flash steam where high efficient quality of steam is pumped into the turbine.

Q41. Explain the process of energy conversion from dry rock geothermal resources. **May-19, (R13), Q9(a)**

OR

With the help of line diagram, explain the heat extraction from hot dry rocks. **April-18, (EEE), (R13), Q9(a)**

OR

With line diagram, explain the heat extraction from hot dry rocks.

Answer : **May-17, (ME), (R13), Q8(a)**

Hot dry rock (HDR) is also called as petrothermal system. In this system heat is extracted from the impermeable (water resistant) rocks that are situated beneath the earths surface. There is no water in these layers. The rocks which are present at a depth of 5 km from the surface posses a temperature greater than 200°C and are considered as the best source of develop t.

In hot dry system, for extracting the heat, the rocks are fractured and cold water is sent through the wells towards the r s. The water extracts heat from the rocks and converts into steam. This steam is extracted through another well, which is made to reach the earth's surface and utilised to generate electricity.

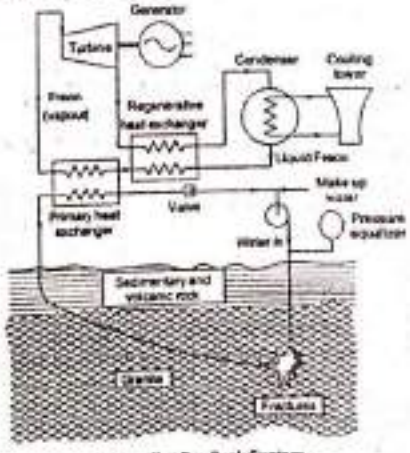

Figure: Hot Dry Rock System

In order to extract the heat from the hot dry rocks, the rocks are fractured which also increases their heat transfer. The various methods to fracture the dry rocks and obtain the geothermal energy are,

1. Detonating a nuclear explosive at the bottom of a drilled well
2. Hydraulic fracturing : Making a large crack in the rocks by pumping water at high pressure. The thickness of the crack might be less than a centimeter but its diameter is hundreds of meters.

Advantages

(i) The process is flexible and can be easily used.

(ii) Steam can be produced in larger amount.

(iii) The life of system is 10 years to 30 years.

(iv) By varying the water supply, the steam required can be regulated.

Disadvantages

(i) Initial cost for setting the system is very high due to deep drilling of wells.

(ii) The leakage of water in the wells is unpredictable.

(iii) The gases from the earths surface can damage the components of the system.

Q42. Explain the following types of liquid-dominated systems.
(i) Binary cycle system (ii) Totalflowsystem.
OR
Draw the line diagram and explain the working of Binary fluid geothermal power system.

Answer : April-10, (EEE), (R13), Q5(a)

(i) Binary Cycle System

A binary cycle system is used widely instead of flash system because of its corrosion resistant property of the working fluids such as Isobutane, Freon-12, etc. These fluids are environmental friendly and causes no pollution. This system works on the principle of closed Rankine cycle. The binary cycle system uses two fluids - one is geothermal fluid and the other is working fluid. Basically, the system consists of a primary heat exchanger, turbine, generator, condenser, cooling tower, etc., as shown figure.

In binary system initially the hot brine from the geothermal well is passed into the heat exchanger in which the heat transfer between the hot brine and the working fluid takes place. This results in the formation of super heated vapour. The vapour then passes through turbine-generator and generates electricity. The vapour from the turbine is sent to regenerative heat exchanger where it cools down. It is further sent to a condenser and cooling tower. The condensed liquid is again sent to primary heat exchanger through rative heat exchanger and the process repeats.

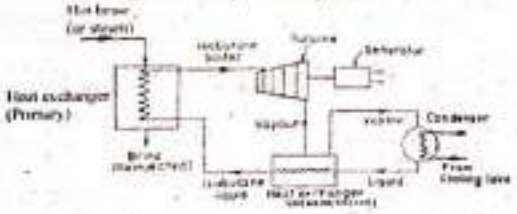

Figure: Binary Cycle System

(ii) Total Flow System

The total flow system is based on the principle of "Lysholm Machine" also known as mixed phase expander. The system consists of a turbine (mixed phase expander), condenser, cooling tower, generator, pump etc.

In this system, the hot brine from the geothermal well is made to pass through the turbine using throttling valve. In turbine the low quality mixture of steam and liquid gets expanded. Since, it is a mixed phase expander the blades of the turbine gets rotated and results in formation of electricity in generator.

The efficiency of turbine-generator depends on the properties of mixed phase expander. The mixed phase expander should be corrosion resistant and should be able to resist the water droplets of the low quality mixture. The remaining mixture is made to pass through condenser, cooling tower into the well using pump.

Q43. What is geothermal energy and explain the types geo thermal power plants?

Answer : July-21 (EEE), (R18), Q4(a)

Geothermal Energy

For answer refer Unit-IV, Q25, Topic : Geothermal Energy.

Types of Geothermal Power Plants

The geothermal power plants are classified as follows.

1. **Vapour Dominated Geothermal Plants**

For answer refer Unit-IV, Q39, Topic : Vapour Dominated System (Exclude Working).

2. **Liquid Dominated Geothermal Plants**

For answer refer Unit-IV, Q40, Topic : Liquid Dominated System.

(i) **Flash System :** For answer refer Unit-IV, Q40, Topic : Flash System (Exclude Working).

(ii) **Binary System :** For answer refer Unit-IV, Q41, Topic : Binary Cycle System.

(iii) **Total Flow System :** For answer refer Unit-IV, Q42, Topic : Total Flow System.

Q44. List the various applications of Geothermal energy. Also specify benefits and limitations of geothermal energy storage.

Answer : May-17, (EEE) (R13), Q6(b)

Applications of Geothermal energy

1. **Electricity Generation :** It can be used for power generation if the temperatures are above 150°C. In countries such as the United States, Italy, New Zealand the energy is used for generating electricity. The energy can be used for generation of base load power. Peak load power generation is not possible due to the effect of scaling and corrosion.

2. **Industrial Process Applications**

(a) Drying of crops

(b) Chemical and textile industries

(c) Food dehydration

(d) Drying of cement slabs in cement industry

(e) Paper manufacturing

(f) Coal drying and gasification

(g) Pasteurizing milk

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3. **Agriculture and Aquaculture :** Geothermal energy is used in greenhouses and in cold places to enhance the growth of crops and also fish in the ponds.

4. **Direct Heating**

(a) **Space Heating :** The heat from the geothermal fluids is used for heating the buildings.

(b) In cold countries, it is also used for cooking, bathing and keeping their houses warm.

Benefits of Geothermal Energy Storage

1. Wastewater is recycled.

2. There is no effect on the minerals in the soil and they are preserved.

3. Less utility costs

4. Less emission of carbon dioxide.

Disadvantages of Geothermal Energy Storage

1. Greatly affected by the surrounding environment

2. The underground heat impacts the storage system

3. It is economical only when injected heat is completely recovered.

Q45. What are the possible sources of geothermal pollution? How to avoid them?

Answer : May-17, (ME), (R13), Q8(b)

Following are the various sources of geothermal pollution and the methods to avoid/reduce them.

1. **Solid Particles and Non-Condensable Gases**

Steam and water contains dissolved solids, solid particles and non-condensable gases. These solid particles are removed from the water with the help of centrifugal separators at the head of the wall and by the strainers. The condensable gases like CO_2, CH_4, H_2, N_2, NH_3 and H_2S in the atmosphere as well as in the water can be removed by the particle centrifugal separators, condenser ejectors and cooling towers.

2. **Water Pollution**

The discharge of heat and toxic substances into rivers causes water pollution, due to which the fisheries and the farming activities are affected. The process of re-injection of geothermal fluid into the reservoir minimizes the surface pollution.

3. **Land Erosion**

This can be controlled by planting shrubs and trees on large scale.

4. **Noise Pollution**

It caused by exhausts, blowdowns, centrifugal separation, etc. It can be minimized by installing silencers on such equipment. The noise caused by the flashing steam can also be eliminated by re-injection.

5. **Water Borne Poisons**

The water borne poisons like toxic mercury, arsenic, ammonia, etc., in wet fields contaminating the downstream and the highly saline bore water can be prevented from mixing and polluting by re-injection and by disposal of these contaminants into sea through ducts, channels and evaporator ponds.

6. **Air-Borne Poisons**

The escape of harmful substances containing radioactive materials into air at thermal [illegible] can be avoided by providing a horizontal well discharge in a controlled direction and by systematic [illegible]

7. **Heat Pollution**

Heat pollution affecting the [illegible] and promoting the growth of unwanted water weeds in heat [illegible] can be controlled by re-injection of surplus cooling tower water and unwanted bore water. It can also be avoided by generating additional power by binary fluid cycle.

8. **Silica**

If water containing silica is re-injected, then there is a possibility of substrate permeability to flow causing change of bore re-injection location. This can be avoided by proper pond settlement.

9. **Subsidence**

The subsidence of ground is also a major problem caused by extracting the geothermal fluids in large quantities from the field. This can be avoided by re-injection, which compensates the quantity of fluid extracted to a considerable extent.

10. **Seismicity**

The long-term exploitation of geothermal energy leads to seismicity and earthquakes. These are caused mostly in areas having high shear stress.

11. **Escaping Steam**

Large amount of flash steam discharged into the air results in dense fog and if drifted on roads causes traffic hazards. This can be avoided by discharging a small amount of steam.

12. **Geo-pressurised Water**

Water flowing with large amount of sand at high flows causes erosion and scaling problem.

Q46. Enumerate the environmental issues associated with utilization of following renewable energy sources.
(a) Geothermal energy and
(b) Open cycle OTEC system.

Answer : May-17, (EEE), (R13), Q4

(a) Geothermal Energy

For answer refer Unit-IV, Q31.

(b) Open Cycle OTEC System

An open OTEC system have the following impacts on the environment.

1. In this system, when the warm water containing CO_2 particles is discharged into the [illegible], it effects the surrounding environment.

2. Due to the circulation of water during operation, living organisms in the ocean are affected and can be killed.

3. Ecosystem surrounding the power plant will have adverse effects as the temperature and nutrients of the [illegible]

4. It also effects the ocean currents and weather.

5. Environment also experiences biological effects due to the discharge of more amount of cold water into the surfaces with warm temperatures.

Q47. Explain about the potential of geothermal energy in India.

Answer : July-13, (R15), Q6(a)

Potential of Geothermal Resources in India

In India, about 340 thermal areas, in the form of hot springs, have been discovered. And, there are 93 systems, which are considered as the total stored heat potential. The total heat potential of these systems is 36.87×10^{17} calories. This is nearly equal to the energy released by burning 5140 million tonnes of coal or 25440 million containers of oil. Among these 93 systems, 38 are used in electrical power generation, as they possess high temperatures. For 100 years, the power generated by these systems is estimated to be about 500 MW and for 30 years, it is 1650 MW. The other remaining systems are used in applications, other than power generation, that have intermediate and low temperatures. They has total stored heat potential of about 19.37×10^{17} calories, but only a part of this potential, i.e., 1.135×10^{17} calories are utilized for practical use. The heat potential of about 2.185×10^{17} calories can be practically utilized, if all the 93 systems are used in applications, other than power generation. For supplying this amount of heat, by means of electricity, nearly 10000 MW of electric power may be required for about 30 years. This value is 10% of the total expected power generation in India by the end of a century.

The geological survey of India have discovered nearly 50 geothermal fields of steam in Puga valley of Ladakh, which are capable of operating a 5 MW power generation plant.

Q48. Discuss the potential of geothermal resource in the world, bringing out the salient points for energy conversion in India.

Answer : May-14, (R15), Q6(a)

Potential of Geothermal Resource in the World

According to the geological survey conducted by United states of America, magnitude of heat corresponding to the temperature above 15°C upto 10 km deep into the earth's crust is said to be geothermal resource. Considering this, geothermal resource in the world may be 2.11×10^{27} J. In order to produce equivalent energy, it is required to burn 10^{9} million tonnes of oil equivalent (MTOE). Corresponding to the current rate of energy usage it will be sufficient for 350000 years.

Pacific plate is the region at which maximum number of world's geothermal fields are located. Pacific plate is also known as ring of fire, since belt of these fields forms a ring around the pacific ocean. Geographical location of these fields includes Argentina, Ecuador, Chile, Peru, Central America, Western North America, Kamchatka, Philippines, Japan, Indonesia and New Zealand. Few geothermal sites are also present in Mediterranean area. Interior continental rifts located in Kenya, Ethiopia and East Africa, and mid ocean ridges present in Azores and Iceland consists of hot crustal material. Deep sedimentary basins in Western Canada, Western Siberia, Gulf coast of United states, Southern Europe and Central Europe consists of low enthalpy geothermal resources.

Geothermal resources available across the world can be used directly for space heating, water heating application and use for power generation. Few countries and their installation capacities are shown in the table below.

Country	Installed Capacity (MW)	
	Direct Application	Power generation
Mexico	156	953
USA	8670	2564
China	3687	25
Japan	822	535
Turkey	1229	20
France	308	15
Iceland	1804	232
Italy	682	810
Russian Federation	308	79
New Zeland	350	435

Salient Points of Energy Conversion in India

For answer refer Unit-IV, Q8.

Q49. Briefly describe different analytical methods to estimate geothermal potential.

Answer : April-18, (ME), (R13), Q6(a)

Estimation of Geothermal Potential

The three methods that are used for the estimation of geothermal potential are as follows,

1. Stored heat method or volumetric method
2. Lumped parameter model
3. Detailed distributed parameter modelling.

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Two of them are discussed below.

Stored Heat or Volumetric Method

This method is used at the initial stage of estimation. In this method, the geothermal potential is estimated by knowing the static reserve of heat in the resource and energy that can be recovered is obtained by applying a recovery factor to it. Estimation of total heat in a reservoir volume is given by the equation,

$$E_T = V\rho_r C_r (1-\phi)(T - T_{ref}) + V\rho_f C_f \phi_f (T - T_{ref})$$

Where,

V – Volume of the reservoir

$V\rho_r C_r (1-\phi)(T - T_{ref})$ – Storage of heat in rock

$V\rho_f C_f \phi_f (T - T_{ref})$ – Storage of heat in the water present in the pores

Recoverable energy,

$$E_R = R_f E_T$$

Where, R_f – Recovery factor

According to Muffler and Cataldi, the recovery factor for geothermal systems of water dominated type is based on the porosity which lies with in the range of 0% at $\phi = 0$ and 25% higher at $\phi = 20$

$$R_f = 1.25\,\phi$$

Amount of heat that can be converted to useful energy will depend on the conversion losses and fraction of energy. Then the equation for economic geothermal resource is given by,

$$E_e = f \times E_R$$

Where, f – Factor of efficiency

Considering above discussed factors and the load factor which gives the operation time of the plant, the equation for geothermal energy conversion to power is

$$P_e = \frac{\text{Available energy} \times \text{recovery factor} \times \text{efficiency factor}}{\text{Load factor} \times \text{life time}}$$

$$\therefore \quad P_e = \frac{E_T \times R_f \times f}{\text{L.F} \times \text{Life time}}$$

Lumped Parameter Modelling

As the stored heat or volumetric method provides static geothermal reserve, it is not appropriate for developing an optimal production strategy of using geothermal energy, it is necessary to generate a model of the system using the parameters defining geothermal reservoir. Thus lumped parameter modelling was introduced which is highly suitable in cases where the availability of time for calculation and data related to reservoir nature are limited.

The principle of this method involves the usage of tanks or boxes with capacitances instead of reservoir. Generally, most of the models use two to three tanks but it may vary depending upon the reservoir complexity. It can be represented as shown in figure below,

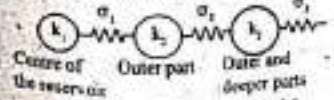

Figure: Lumped Parameter Model

This method is used for calculating pressure response data related to the energy produced from the reservoir. For a lumped parameter model, the pressure response is given by,

$$p(t) = -\sum_{i=1}^{N} Q \frac{A_i}{L_i}(1 - e^{-L_i t}) \quad \ldots (1)$$

Where,

N – Number of tanks

Q – Heat for energy

t – Time

Equation (1) represents pressure response of open model with number of tanks. In this, the pressure is constant.

$$p(t) = -\sum_{i=1}^{N-1} Q \frac{A_i}{L_i}(1 - e^{-L_i t}) + Qbt \quad \ldots (2)$$

Equation (2) represents a pressure response of closed model with one equivalent tank. The pressure in this system changes as the production starts.

Where, A_i, L_i and B are coefficients which are the functions of coefficient of storage of the tank k_i and the coefficient of the conductance of the resistors σ_i

Storage coefficient of a tank is given by,

$$k_i = V_i s$$

Where,

V_i – Tank volume

s – Ability of storage of the tank

$= \rho_r \times (\phi C_w + (1-\phi) C_r)$ —

4.2 Ocean Energy

4.2.1 OTEC – Principles – Utilization – Setting of OTEC Plants – Thermodynamic Cycles

Q50. Explain the process of energy conversion from oceans. [May-19, (R15), Q6(b) | Model Paper, Q7(a)]

OR

Explain the principle of ocean thermal energy conversion. (OTEC)

Answer : [July-21, (ME), (R15), Q6(a) | May-15, (R05), Q7(b)]

Working of an OTEC System

The concept of Ocean Thermal Energy Conversion (OTEC) was first introduced by a French physicist J.D. Arsonval. It is based on ocean thermal gradient principle of thermodynamics. It states that 'If a heat source is available at higher temperature and a heat sink at lower temperature, then it is possible to utilize the temperature difference to operate a machine or prime mover such as turbine, which can convert a part of heat taken from the source into mechanical energy and hence into electrical energy by using a generator. The remaining heat is discharged to the sink at lower temperature.

The surface of sea water acts as a solar heat collector. The surface of the sea will have higher temperature, and is considered as heat source. The water at deeper levels at the sea are at relatively lower temperatures, and is considered as 'heat sink'. This temperature gradient can be utilized to run a heat engine to generate power. This is known as ocean thermal energy conversion (OTEC).

Let,

T_1 = The temperature of the upper surface layer

T_2 = The temperature of the cold water in deep ocean.

Then the Carnot efficiency of the heat engine is given by,

$$\eta_{carnot} = \frac{T_1 - T_2}{T_1}$$

The actual efficiency of a practical OTEC plant is less than 2%.

Q51. Describe the open cycle OTEC power plant and give the status of OTEC plants in India.

Answer : June-18, (R13), Q9(a)

Open Cycle or Claude Cycle

The open cycle OTEC system is also known as Claude cycle. It uses sea water as the working fluid. The schematic diagram of a open cycle OTEC is shown in below figure.

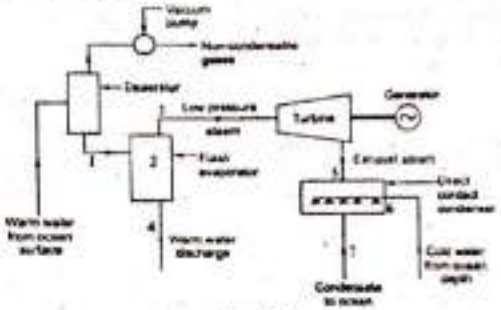

Figure (1)

The warm water from the ocean surface is supplied to the evaporated through a degassifier deaerator. In the evaporator the warm water is flash evaporated under vacuum (the evaporator pressure is maintained slightly below the saturation pressure corresponding to the warm water). Thus, a low pressure steam is produced. Then the steam expands in a turbine which is coupled to a generator to produce electricity. After expansion, the exhaust steam from the turbine is passed to a direct contact type condenser. In the condenser, the exhaust steam mixes with the cold water brought up from the deep ocean, and the mixture of condensed steam and ocean cold water is discharged into the ocean. The thermodynamic cycle of open cycle OTEC is shown in below figure.

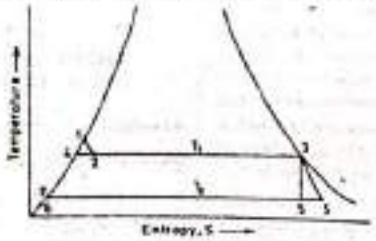

Figure (2)

Status of OTEC Plants in India

(i) In India, the Department of Non-conventional Energy Sources also known as DNES has proposed to install a 1 MW OTEC plant in Lakshadweep Island at Minicoy and Kavaratti.

(ii) Preliminary oceanographic studies on the eastern side of Lakshadweep Island indicates the possibility of the establishment of shore based OTEC plant at the Island.

(iii) The OTEC plant will bring up the water from 1000 m depth which has large nutrient value.

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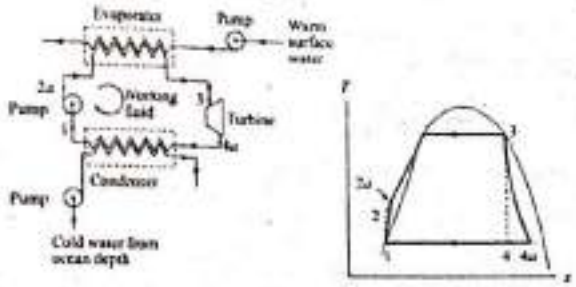
Q52. Explain the closed cycle OTEC plant and list out the major problems associated OTEC.

Answer : April-18, (ME), (R13), Q9(a)

Closed Cycle OTEC Plant

The closed cycle OTEC system is also known as the Rankine cycle or Anderson OTEC cycle, in which the low boiling point working fluids such as ammonia, propane, R22, etc, are used as working fluid. The warm surface water from the ocean is supplied through an evaporator. The evaporator acts as a boiler, in which the high pressure working fluid absorbs heat and converted into vapour. This vapour is supplied to a turbine, where it expands and develops mechanical power, which runs a generator to produce electricity. Then the expanded vapour coming out of the turbine is condensed in a condenser with the help of cold water brought up from the ocean depths through a pump and cold water pipe. The condensed liquid is pressurised with the help of a pump before being fed into the evaporator again, thus this cycle is a closed cycle. The schematic diagram and thermodynamic representation of the closed cycle OTEC is shown in below figure.



Figure

Problems Associated with OTEC

For answer refer Unit-IV, Q55, Topic: Disadvantages of OTEC Plant.

Q53. Describe the Closed cycle OTEC system with its advantages over Open cycle OTEC system.

Answer : July-21, (R16), Q8

Closed Cycle OTEC System

For answer refer Unit-IV, Q52, Topic : Closed Cycle OTEC Plant.

Advantages Over Open Cycle OTEC System

The improvements in closed cycle generation can be proposed by modifying certain components of open cycle ocean thermal energy conversion system.

These are as follows,

1. By adding an improved evaporator which is known as "controlled flash-steam evaporator".
2. By replacing surface condenser with direct contact condenser.
3. By using a plant for cogeneration of electric power and fresh water.

The above modifications helps in increasing the efficiency of the plant.

Q54. Explain the hybrid cycle operation of OTEC plant with a neat diagram. Dec.-20, (R16), Q8

OR

Draw line diagram and explain the Hybrid cycle and its working. April-18, (EEE), (R13), Q9(a)

OR

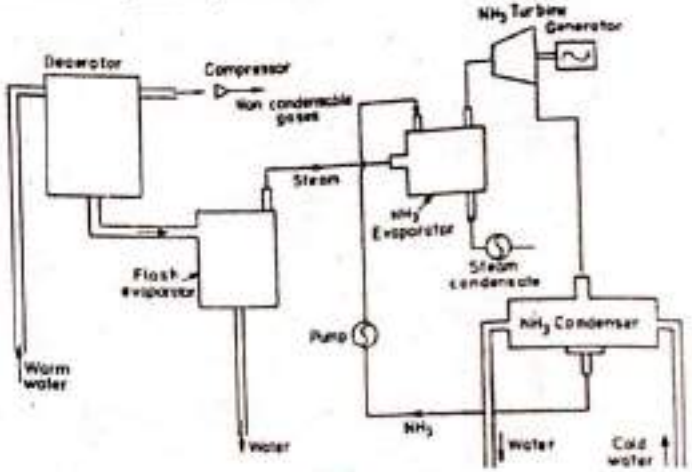
Draw the line diagram and explain the working of hybrid OTEC cycle.

Answer : May-17, (ME), (R13), Q9(a)

Hybrid Cycle- Ocean Thermal Energy Conservation (OTEC) Systems

In hybrid cycle, the best features of both closed-cycle system and open-cycle system are combined and the worst features are eliminated.

In this system initially, the warm sea water is flash evaporated to steam, similar to an open cycle OTEC system. Then the heat in the steam produced, is supplied to the ammonia based closed cycle OTEC system. The ammonia gas is then led to the turbine that is coupled to the generator to produce electricity. The exhaust steam from the turbine goes to a condenser, where it is condensed with help of cold water brought from the deeper levels of the ocean. The condensate is pumped back to the evaporator to repeat the cycle. The schematic diagram of a hybrid OTEC system is shown in below figure.



Figure

Q55. What are the advantages, limitations of OTEC plants?

Answer :

Advantages of OTEC Plant

1. OTEC plants produce power which is pollution free.
2. It does not require land area.
3. Fresh water is produced as a by-product in modified open cycle OTEC system, and in closed cycle system, when integrated with desalination plant.
4. It becomes a special alternative source of energy for remote islands.
5. The power can be produced even in mid-sea with the use of floating type OTEC system.
6. It is considered as a steady source of energy, since temperatures in the sea are almost steady.
7. The ocean thermal energy is freely available.

Disadvantages of OTEC Plant

1. Due to the low temperature differences, the plant efficiencies are very low. Thus, to obtained the required power output plant size should be very large which results in huge capital cost.
2. Incase of open cycle OTEC, many problems are associated with the design, operation and maintenance of the evaporator.
3. For closed cycle OTEC systems, the size of the heat exchangers, both the evaporator and condenser is larger than that of conventional plants.
4. The pumps should handle larger amounts of water, which reduces the net power output.
5. For an OTEC power plant with 100 MW capacity, 1 km long and 30 m diameter pipe is required.
6. The distribution of electric cables from the plant to the shore should be done very carefully, since the cables are subjected to various stresses such as its own weight, ocean currents and eddies.
7. The OTEC plant should be capable of withstanding many ocean storms during its life time, corrosion caused by the water, erosion and bio-fouling.
8. In flash evaporators, to maintain vacuum large vacuum pumps are required.
9. The construction of floating power plant is very difficult.

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Q56. Explain the OTEC scheme and mentions its limitation.

Answer : May-17, (EEE), (R13), Q6(b)

OTEC Sheme

For answer refer Unit-IV, Q50.

Limitions of OTEC

For answer refer Unit-IV, Q55, Topic: Disadvantages of OTEC Plant.

4.2 Tidal and Wave Energy Potential and Conversion Techniques – Economics

Q57. What is the difference between tidal energy and wave energy?

Answer : July-19, (R15), Q1(g)

	Tidal Energy		Wave Energy
1.	It refers to the hydro energy in ocean tides.	1.	It refers to the waves of water from ocean to the shore.
2.	Tides occur due to the gravitational attractive forces from the sun and the moon.	2.	Waves occur due to the rotation of the earth and the winds over ocean surface.
3.	The water level in ocean rises periodically during high tides and drops during low tides.	3.	Wave have an interval of 4 to 12 seconds. Usually the crest of a waves varies from few centimetres to about 10 m.
4.	The difference in water heads during high tide and low tide is used for rotating hydroturbine generator.	4.	The wave energy rotates the rotor of the wave machine.

Q58. Explain in detail about different types of conversion techniques for tidal energy.

Answer : July-19, (R15), Q8(a)

Types of Conversion Techniques for Tidal Energy

There are three techniques available for conversion of tidal energy into electrical energy. They are tidal barrages, tidal lagoons and tidal turbines.

1. **Tidal Barrages**

Tidal barrages are similar to that of dams employed in hydroelectric power plants. But, tidal barrages are quite bigger than dams. Constructions of tidal barrages is carried out across an Estuary or a Bay. Minimum value of tidal range i.e., difference between high and low tide should be by 5 m, in order to generate power using the tidal barrage. During high tide period, ocean water enters into the basin through the barrage. The gates of the system gets closed, when the tides become less intense. Thereby ocean water gets trapped in the basin. During low tide period, gates are opened, water flow out of the basin through turbines. This causes turbines to rotate and eventually the power is developed.

Tidal barrage is the most efficient tidal energy conversion technique. But it has negative impact on environment of the locality at which barrage is located and also upfront capital costs involved are high.

2. **Tidal Lagoons**

Working principle of tidal lagoons is same as that of tidal barrages but differ in construction and location. It is smaller in size and located away from the ocean. During high tide period, ocean water is allowed to flow into the lagoons through canal connecting ocean and lagoon. During low tide period, water flows out through an opening in which turbine is located. Thereby, turbine rotates and eventually power generations takes place.

Tidal lagoons does not have any devastating effects on the environment and their upfront capital cost is also low.

3. **Tidal Turbines**

They resemble the windmills, but difference is that they are located underneath the water. Tidal turbine blades are shorter and of higher strength when compared to that of wind mills. Rotation of turbine is caused by ocean water currents. When turbine turns electricity is generated as turbine is coupled to the generator.

Tidal turbines are environmental friendly and their installation cost is high.

Q 59. What is the source of tidal energy. What is the minimum tidal range required for the working of a tidal plant? How much is the potential in tides?

Answer : April-18, (ME), (R13), Q60

Sources of Tidal Energy

Tides are periodic rise and fall of ocean water level, which occur generally twice in each lunar day. The gravitational pull of moon and to a lesser extent the sun, on the earth gives rise to a bulge in the oceans on side facing of moon. On the opposite side of the earth a second bulge creates centrifugal force due to its rotation. The two bulges are high tides and the areas between the bulges are low tides. Tidal energy harnesses the K.E of the ebb and flow of the tides. Tidal flow turbines are similar to wind turbines mounted on the sea bed. Tidal barrages or dams are constructed across the passage of incoming tide.

Tides are driven by the moon's rotation around the earth and waves are driven by the wind blowing across the surface of the water. The main difference is probably the period i.e., tides have a period of several hours, since there are one or two tidal peaks in a day, because it takes a while for the moon to get around the earth, while waves have a short period of few seconds.

Minimum Tidal Range

Minimum tidal range is defined as the difference between the level of mean high tide and low tide.

For a tidal plant operating with conventional equipment, the value of minimum tidal range is 5 m. Whereas, for a tidal plant with low-head equipment is about 2 m.

Tidal Power Potential

For answer refer Unit-IV, Q64.

Q60. Explain different components of Tidal power plants in detail. April-18, (EEE), (R13), Q60

OR

What is tidal energy? What are the elements of tidal energy power generation system?

Answer :

The periodic rise and fall of the sea level relative to the land is called as tide. Attraction of sea by the moon results in tides. Tidal power is a renewable source of energy and is a form of hydro energy. The energy obtained from tides can be converted to mechanical energy using hydro turbines which in turn converted to electrical energy by generators. The energy generation from tides depends upon the heights of the tides. The height of the tide must be either above or below the level of tidal basin in order to operate the turbine unit. When height of the tide and the level of the tidal basin are equal, it is not possible to operate the turbine.

The power or energy generation system of tidal energy includes the following elements.

1. **Tidal Basin:** A shallow coastal inlet or bay that is used to store and discard the water as the tide rises and falls respectively is known as tidal basin.
2. **Dam (or) Barrage:** It is a wall constructed across the tidal path i.e., in between sea and tidal basin to trap the water from either going into basin during high tides or going out of basin during low tides. The turbine unit is installed within the barrage tunnels or it may be connected to the barrage.
3. **Power House:** It consists of turbines, generators and other auxiliaries.
4. **Turbine:** It gets operated when water flow occurs from sea to basin and vice versa, which convert the energy possessed by water into mechanical energy. Usually following types of turbines are used in tidal power plants,
   (i) Bulb turbines
   (ii) Rim turbines
   (iii) Tubular turbines.
5. **Sluice Openings (gates):** The flow of water to the basin is controlled by operating sluice gates to avoid overflow or under flow.
6. **Generator:** It is connected to output shaft of turbine so as to convert the mechanical energy from turbine to electrical energy.

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Power generation during high tides and low tides including various parts it illustrated in figures below

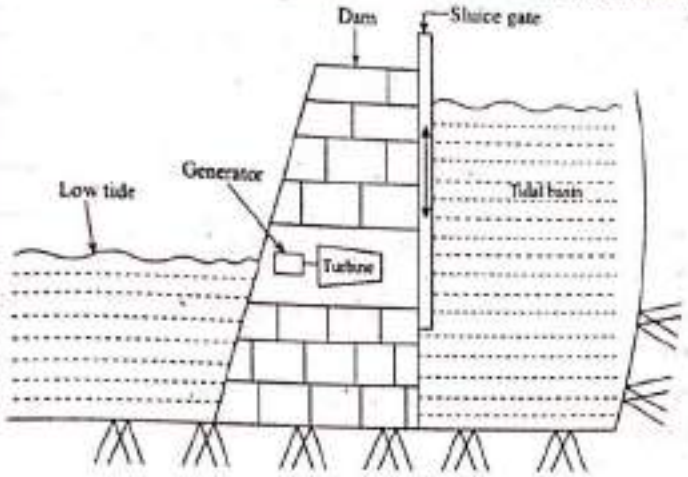


Figure (1): Power Generation from Low Tide

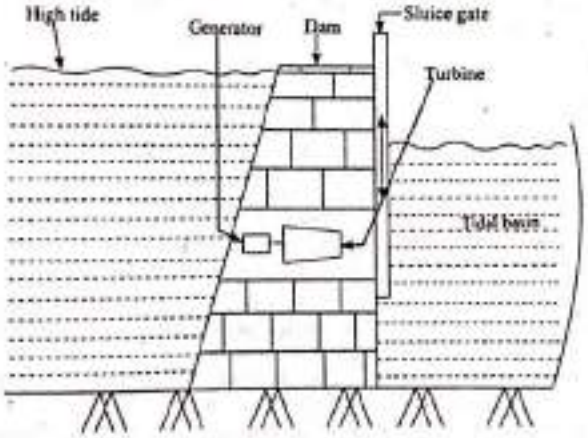


Figure (2): Power Generation from High Tide

Q61. What are the advantages and limitations of tidal power generation.

Answer :

Advantages of Tidal Power Generation

1. It does not require large area of land.
2. Power generation is free from pollution.
3. Peak power demand can be effectively met, when the tidal power plant works in combination with hydroelectric or thermal power plant.
4. Tidal power does not depend on the rain fall. Thus, there is no uncertainity in tidal energy availability.
5. It is inexhaustible and a renewable source of energy
6. The net cost associated with the tidal plant is less.

Limitations of Tidal Power Generation

1. The construction of tidal plant in sea is difficult.
2. The output tidal energy changes with the variation in the tidal range (R).
3. When compared to other renewable sources of energy, the tidal power plants are costly.
4. The tidal power plants are located away from the load centres, the cost of power transmissions is high.
5. The machinery may get corroded because of the sea water.
6. The efficiency of tidal plant is affected, since the turbines have to work on a wide range of head variation.
10. Sedimentation and silterations of tidal basins is a common problem.

Q62. Explain the various methods for the utilization of tidal energy.

OR

Distinguish between single basin and double basin arrangement for generation of electricity from tidal energy.

Answer : July-21, (ME), (R16), Q8(b)

The following two arrangements are used for the utilization of tidal energy.

1. Single basin arrangement
2. Double basin arrangement.

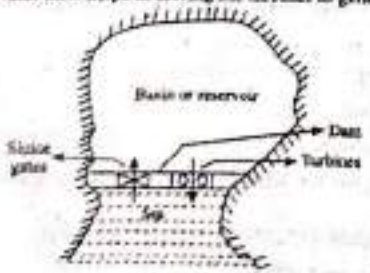
I. **Single Basin Arrangement:** A single basin arrangement consists of a single basin and a dam that separates the basin with the sea. The flow between the sea and basin is regulated by sluice ways located on the dam. In this system, the power can be generated using any one of the following systems.

(i) **Single Basin Single Effect:** There are two types of operation cycles. They are,

(a) **Ebb Generation:** When there is a high tide in the sea, the water is allowed into the basin by opening the sluice gates. During this process, the turbines sets are closed. The water flows into the basin till it attains the maximum tide level. When the ebb begins, the sluice gates are closed and the back flow of sea tank place. Then, the water from the basin flows through the turbine sets into the sea water, which results in the power generation. The turbines are operated only when there is a desired difference between heads of basin water and sea water and are made to run till the effective head on them is reduced by the next high tide level and falling reservoir level. When the head is reduced, the turbines cannot work in an efficient manner. Then, the gates are opened again and the turbines are closed. This process of operation is repeated as a cycle.

(b) **Flood or Tide Generation:** In this system, when there is a high tide, the water is passed into the basin through the turbines, resulting in power generation. But, when the tide falls, the sea water level decreases, thus causing no power generation. Then, the turbines are closed and sluice gates are opened to drain away the water in the basin back into the sea. This tide cycle system is less efficient, when compared to ebb system, as it operates for shorter duration. However, turbines can be made to operate for longer periods, by suitable methods.

(ii) **Single Basin Double Effect:** In this system, both ebb and flood tides enables the power generation. The direction of water flow through the turbines during both the tides changes. When the sea is at high tide and reservoir is at low tide level, the filling of basin takes place, while emptying takes place, when the sea is at low tide level and basin is at high tide level. Therefore, both the directions of water flow helps in driving the turbines to generated power.



Figure(1) : Single Basin Arrangement

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Double Basin Arrangement: In double basin arrangement, two basins called upper basin and lower basin are arranged. The water level in the upper basin must be higher than the lower basin, as the difference in their heads can be used to generate the electricity. Similar to single basin arrangement, sluice gates are located on the dam of the two basins and the turbines are placed between the two basins as shown in figure (2).

When there is a high tide, the sluice gates of upper basin are open to allow the sea water into it. During this process, the gates of lower basin and the turbine sets are closed. As the upper basin is filled and lower basin is empty, difference of head is created and then, the turbines are operated. Thus, the water from upper basin flows into lower basin through the turbines, thereby generating electric power. The sea water flows into the upper basin continuously, while it is being emptied by allowing the water into the lower basin till the end of high tide in sea. If water in the upper basin reaches the maximum level, the sluice gates are closed. Then, the sluice gates of lower basin are opened and the water flows into the sea, thus reducing its level with respect to the falling ebb tide. This process is continued till the availability of sufficient head. When the next high tide occurs, the process is repeated.

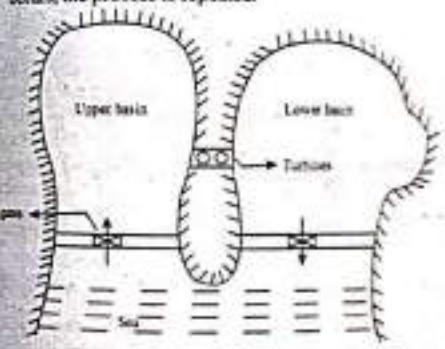


Figure (2) : Double Basin Arrangement

Q63. Explain the working of single basin tidal power plant.

Answer : May-17, (ME), (R13), Q8(b)

For answer refer Unit-IV, Q62, Topic: Single Basin Arrangement.

Q64. Write a short note on the potential of tidal energy in India.

Answer :

Tidal energy is a form of hydropower energy, which uses the energy of the oceanic tides to generate electricity.

India has a long coastline of 7500 km with immense potential for ocean energy.

According to a study by IIT Chennai and CRISIL (an Indian analytical company) in december of 2014, the tidal power potential of the country is estimated at about 12,455 megawatt (MW).

The potential areas of tidal energy are in the Gulf of Khambhat, Gulf of Kutch and southern regions in Gujarat, Palk Bay-mannar Channel in Tamil Nadu, and Hoogly river, South Haldia and Sunderbans in West Bengal.

The estimated potentials are as follows,

1. Gulf of Kambhat is about 7000 MW.
2. Gulf of Kutch near Gujarat is about 1200 MW.
3. Sunderbans is about 100 MW.

India had shown an interest towards the tidal energy in 2911, when the 50 MW tidal energy plant was established in Gujarat. Globally, tidal energy plants are limited with only 500 MW capacity, while the South Korea is leading the actual and planned investments.

Q65. Explain various devices used for wave energy conversion.

Answer : May-13, (R09), Q7(a)

The wave machines are used to convert the potential energy and kinetic energy present in water to mechanical energy.

The different types of wave energy conversions are classified according to the following parameters.

(a) **According to Location**
   (i) Shoreline machines
   (ii) Deep water (or) off shore machines

(b) **According to Position with Respect to Sea Level**
   (i) Floating wave power machine
   (ii) Submerged wave power machine
   (iii) Partially submerged machines

(c) **According to the Actuating Motion used in Capturing the Wave Power**
   (i) Heaving float type
   (ii) Surge type
   (iii) Oscillating water column type
   (iv) Pitching type
   (v) Heaving and pitching float type

Q66. Enlist advantages and disadvantages of wave energy.

Answer :

Advantages of Wave Energy

1. It is free and renewable energy source.
2. The devices associated with wave energy are relatively pollution free, because they extract the energy from waves and leave the water in a placid state.
3. Unlike solar or wind, the wave power devices do not use large land masses.
4. The wave power devices produce electricity, and also protect the coast lines from the damage caused by large waves, minimise erosion, etc.
5. The wind energy is naturally concentrated by accumulation overtime and space, and this energy can be transported from its origin to other locations through the wind.

Disadvantages of Wave Energy

1. Wave energy plants require huge capital investment, maintenance cost, repair and replacement cost.
2. It is difficult to identify the accessible site of large wave activity.
3. The design of wave energy conversion devices is relatively complicated.
4. Lack of dependability.
5. Wave energy converters should be capable of withstanding severe peak stresses during storms.

Q67. Describe the construction and working of any one type of wave energy conversion machine.

Sept.-20, (R16), Q8(a)

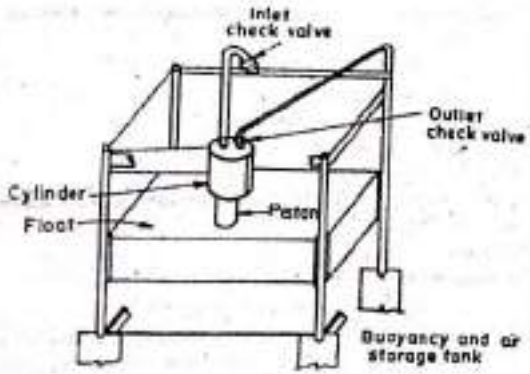
OR

Explain briefly about the construction and working of float wave power conversion device.

Answer : Model Paper, Q9(b)

The wave motion is primarily horizontal, but the motion of the water is primarily vertical. The floats make use of the water motion and produce the mechanical power. In float wave power machines, a large float is driven up and down by the water within relatively stationary guides. This reciprocating motion of the float is converted to mechanical energy and then to electrical power.

Schematic diagram of Martin's float wave power machine is shown in below figure.



Figure

As shown in figure, the machine consists of four vertical manifolds that are part of the platform and guides a square float that moves up and down with the water. The platform is stabilised by four large under water flotation tanks. The platform supported by buoyancy forces and there is no vertical or horizontal motion due to wave action. Thus, the platform is stationary on the ocean surface.

A piston attached to the float moves up and down inside a cylinder, which is attached to the platform thus it is relatively stationary. Here, the piston and cylinder arrangement acts as a reciprocating compressor.

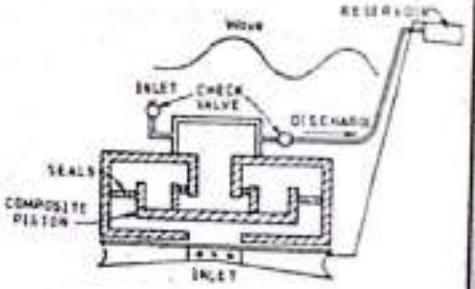
When the piston moves downward, the air sucked into the cylinder through the inlet check valve. The upward motion of the piston compresses the air and is supplied to the four underwater flotation tanks through the outlet check valve and the four vertical manifolds. Therefore, the flotation tank serves dual purpose, buoyancy and storage of air.

The compressed air in the buoyancy - storage tank is used to run and air turbine, which in turn run an electrical generator to produce electricity. The electricity is transferred to the shore through underwater cable.

Q68. Explain the working principle of high-line reservoir wave machine.

Answer :

The construction and working principle of high-line reservoir wave machine is shown in below figure.



Figure

In this machine a magnification piston is used. The pressurised water from the piston is elevated to a saline reservoir (should be located near the shore line) above the wave generator or to an artificial water reservoir. The water from the reservoir is made to flow through a turbine which is coupled to an electric generator to produce the electricity. Then the water from the reservoir is made to flow back to sea level. With the use of this machine, a generator of 20 m diameter can produce 1 MW power.

Q69. How does the oscillating wave column convert energy into mechanical from?

Answer : May-19, (R15), Q8(b)

Oscillating Water-Column Device

In the oscillating water-column device, a concrete or steel structure is partly submerged. It has an opening to the sea below the water line, and also encloses a column of air above the column of water as shown in below figure.

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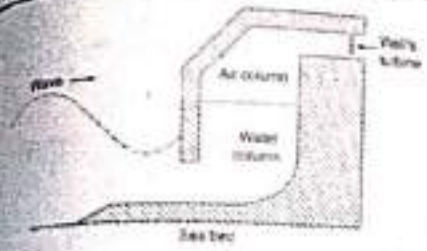

Figure

When the wave strikes on this device, the water column rises and falls alternately and corresponding the air column also compressed and depressurised alternately. The air is made to flow through turbine, which is coupled to a generator. In this type of wave energy systems, axial flow well's turbine, which can be operated with the either directions of air flow is used to extract the wave energy.

The oscillating water column type device has following important advantages.

1. The velocity of air can be increased by reducing the cross section of the air channel. Therefore, the slow wave motion can be effectively used with the high speed turbines to extract the energy.
2. Power producing equipments are kept away from the immediate salase waters.

Q70. Show that wave power is directly proportional to the square of amplitude and inversely proportion to the period of wave.

Sept.-20, (R16), Q8(b)

OR

Show that wave power is directly proportional to the square of amplitude and inversely proportional to the period of wave.

Answer : June-18, (R15), Q9(b)

Note: The question given in University paper is not correct. The question should be,

'Show that wave power is directly proportional to the square of amplitude and to the period of wave'

Consider an ideal deep-water surface wave as shown in figure as,

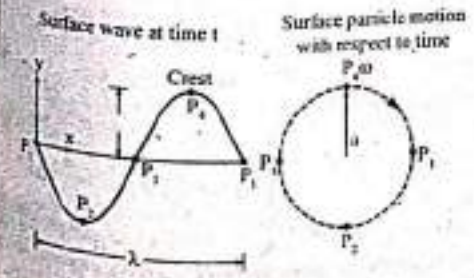

Figure (1)

The motion equation of wave is given as,

$$y = a \sin\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right) \quad ...(1)$$

Where,

y – Displacement above mean sea level

a – Amplitude of wave

λ – Wave length of wave

T – Time period of wave

t – Time of travel.

The equation (1) can also be written as,

$$y = a \sin(kx - \omega t) \quad ...(2)$$

Where,

Wave number, $K = \frac{2\pi}{\lambda}$

Angular frequency, $\omega = \frac{2\pi}{T}$ rad/s

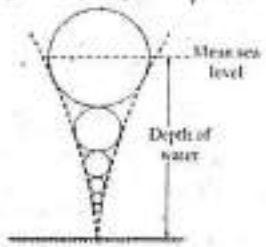

Figure (2)

When wave moves in linear direction, i.e., along x – axis, every particle of water at the surface undergoes a circular motion with radius 'a' (amplitude of wave) and angular speed ω.

This type of motion is observed when a body is suspended in the water. The figure (2) shows the cross section of water column, in which the radius of circular motion of water particle decreases continuously as it travels to deep and becomes zero at the sea bed. Hence, when the wave propagates in the x – direction, net flow of water is zero.

The wavelength of the wave in given as,

$$\lambda = \frac{2\pi g}{\omega^2} \quad ...(3)$$

Then, $\omega = \sqrt{\frac{2\pi g}{\lambda}}$

The time period of wave motion is given as,

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\frac{2\pi g}{\lambda}}} = \sqrt{\frac{2\pi\lambda}{g}} \quad ...(4)$$

The linear velocity of the particle at the crest of the wave is given as,

$$v_c = a\omega$$

The wave velocity in the x – direction is given as,

$$v = \frac{\omega\lambda}{2\pi} = \frac{\lambda}{T} = \frac{\omega}{k} = \frac{g}{\omega} \quad ...(5)$$

From equation (5), it is observed that the wave velocity is independent of amplitude.

Consider unit width of the wave front perpendicular to the direction of motion of wave as shown in figure (3).

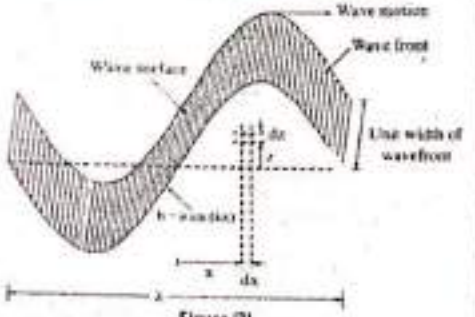

Figure (3)

At time, $t = 0$

The vertical displacement at water particles in given as,

$$h = a\sin(kx)$$

Consider an element of water with thickness 'dx' and height 'dz', which is at a distance x and height z.

Mass of the water element, $dm = \rho.dx.dz.1$

$$\therefore dm = \rho dxdz$$

If the element moved from $-z$ to $+z$, then the potential energy of the element is given as,

$$dE_p = (\rho dxdz)g \times 2z \qquad (\because P.E = mgh)$$

Then, the total potential energy of wavefront per one wave length is given as,

$$E_p = \int_{x=0}^{x=\frac{\lambda}{2}} \int_{z=0}^{z=h} dE_p$$

$$= \int_{x=0}^{x=\frac{\lambda}{2}} \int_{z=0}^{z=h} (\rho dxdz)g2z$$

$$= \rho g \int_{x=0}^{x=\frac{\lambda}{2}} \left[2\frac{z^2}{2}\right]_0^h dx$$

$$= \rho g \int_{x=0}^{x=\frac{\lambda}{2}} h^2 dx$$

$$= \rho g \int_{x=0}^{x=\frac{\lambda}{2}} a^2\sin^2(kx)$$

$$= \rho g a^2 \int_{x=0}^{x=\frac{\lambda}{2}} \sin^2(kx)dx$$

$$= \rho g a^2 \int_{x=0}^{x=\frac{\lambda}{2}} \frac{(1-\cos 2kx)}{2}dx$$

$$= \frac{1}{2}\rho g a^2\left[\int_{x=0}^{x=\frac{\lambda}{2}} 1.dx - \int_{x=0}^{x=\frac{\lambda}{2}} \frac{\cos 2kx}{2}\right]$$

$$= \frac{1}{2}\rho g a^2\left[(x)_0^{\frac{\lambda}{2}} - \frac{1}{2k}[\sin 2kx]_0^{\frac{\lambda}{2}}\right]$$

$$= \frac{1}{2}\rho g a^2\left[\frac{\lambda}{2} - \frac{1}{2k}\left[\sin 2k\frac{\lambda}{2} - \sin 0\right]\right]$$

$$= \frac{1}{2}\rho g a^2\left[\frac{\lambda}{2} - \frac{\lambda}{2.2\pi}[\sin 2\pi - 0]\right]$$

$$= \frac{1}{2}\rho g a^2\left[\frac{\lambda}{2} - 0\right]$$

$$\therefore \quad E_p = \frac{1}{4}\rho g a^2 \lambda \qquad ...(6)$$

Potential energy per unit length and per unit width of wave front (i.e., per unit surface) is given as,

$$E_p = \frac{1}{4}\rho g a^2 \qquad ...(7)$$

In harmonic motion, the potential and average kinetic energies are equal.

$\therefore$ Kinetic energy per unit area, $E_k = \frac{1}{4}\rho g a^2$ ...(8)

Total energy per unit surface area is,

$$E = E_p + E_k$$

$$= \frac{1}{4}\rho g a^2 + \frac{1}{4}\rho g a^2$$

$$= \frac{1}{2}\rho g a^2 \text{ J/m}^2$$

Then, the power carried forward per unit width of wave front,

$$P = Eu$$

$$= \frac{1}{2}\rho g a^2 \times \frac{v}{2} \text{ W/m} \qquad ...(9)$$

Where, $u = \frac{v}{2}$ is group velocity of deep water waves.

Then,

$$P = \frac{1}{2}\rho g a^2 \times \frac{g}{2\omega}$$

$$= \frac{1}{4}\rho g^2 a^2 \times \frac{1}{\omega}$$

$$= \frac{1}{4}\rho g^2 a^2 \times \frac{1}{\frac{2\pi}{T}}$$

$$= \frac{1}{4}\rho g^2 a^2 \times T \qquad ...(10)$$

Therefore, the power in waves is directly proportional to the square of the amplitude and to the period of wave.

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Q71. Write about wave power development in India.

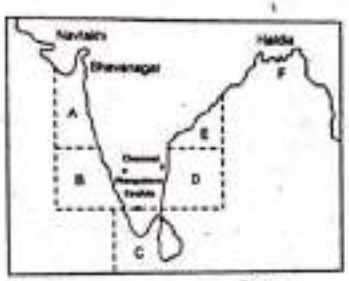
Answer :

Wave Power Development May-15, (R09), Q7(a)

In 1799, Girard filed a patent about the proposal of developing wave machines. He visualised a wave machine by connecting a floating anchored ship to the mechanism and pump, which is placed on the shore using a rod. With the help of mechanism and rod, the ship exhibits oscillating motion in vertical direction, whereas the horizontal movement is restricted. This oscillating motion of the shaft or rod was then converted into rotary motion with the help of mechanism, by which the pumps are driven. Oceanographers and physicists further examined this wave phenomenon during 1890s. Then, for experimentation purposes, a small sample or model of different types of wave machines were built in the countries like USA, UK, Japan and Canada in the period 1910 to 1950. And, in 1959, a pumped storage system with the capacity of 5 MW was setup. Later, in 1965, due to the decrease in oil prices, it became insignificant. During 1976, the assessment of the scheme has been done and the proposal of constructing 28 MW system was approved. Then, many models of plants with capacities 100 to 500 kW were constructed after 1973, due to the rise in oil prices. Small capacity wave power engines are used for installation purposes on light houses, remote islands, etc., which are marketed by Japan. Also, large base load power plants were used in 'Mauritius' in 1976.

Wave Power Development in India

The various zones around India with higher wave energy potential and suitable for wave power development are shown in the figure.



A,B, C, D, E, F - Zones of wave power around India

Figure

The potential of wave energy varies from west coast to east coast as per the estimation of wave energy distribution estimation. It is of 39 kW and 15 kW on the west and east coasts respectively. According to the average estimation, the total potential of power on a 6000 m coastline with 15 kW/m potential is 90000 MW.

4.3 Mini-Hydel Power Plants – Economics

Q72. What are the types of hydroelectric power plants?

Answer :

Hydroelectric power plants are classified based on the following parameters,

1. **Purpose**

Hydroelectric power plant may be for single purpose i.e., only electric power production or as multi purpose plant which includes flood control, irrigation, drinking water, fisheries, tourism and navigation purpose in addition to electric power production.

2. **Location and Topography**

(i) Plain or hilly area plants

(ii) Low land plants

(iii) Mountain region plants.

Hydropower plants are mostly located in hilly and mountain areas in order to obtain different advantages such as ease in the construction of dams, large capacity reservoirs, irrigation and other multi-purpose applications.

3. **Plant Capacity**

Mini hydroelectric plants: 100 kW upto 2 MW

Small hydroelectric plants: 2 MW to 15 MW

Medium hydroelectric plants: 15 MW – 100 MW

High capacity hydroelectric plants: 100 MW – 1000 MW

Super hydroelectric plants : Above 1000 MW.

4. **Civil Constructional Features**

(i) **Run off River Plants:** These are installed along the main stream of river, with or without reservoir formation.

(ii) **Valley Dam Plants:** These may be constructed to create water storage and the power plant is located at foot of dam. Water is stored during floods season and is used for remaining period for different purposes apart from hydroelectric power production.

(iii) **Diversion Canal Distribution Plants:** These are such plants, in which water is diverted from river through canal to power house, located little faraway from water source. After water is used for power generation, water is let out down stream of plant and again connected to main river at down stream point.

5. **Available Head**

(i) **High Head Plants (H > 100 m):** If hydraulic head is more than 100 m the plants are known as high head plants. Even sometimes head choice to 1000 m, safe spillways are very much needed for such plants. Pelton wheel is employed for prime mover. Water from main reservoir is first carried by tunnel upto surge tank and then carried through penstock to power house. Surge tank reduces the water hammer effects on penstock.

(ii) **Medium Head Plants (30 ≤ H < 100 m):** If hydraulic head is between 30 and 100 m, power plants are categorized as medium head plants. Francis, Kaplan turbines are used as prime movers in these plants. Water is carried through penstocks to power house. It has forebays as temporary reservoirs to reduce water hammer on penstock.

(iii) **Low Head Plants (H ≤ 30 m):** If hydraulic head is below 30 m, then it is low head plant. Head is low, thus water is not carried through penstock to power house. But, power plant is located near dam itself. No surge tank is required. Propeller and Kaplan turbines are used.

6. **Operation or Duty**

(i) **Base Load Plants:** Plants supplying base loads which is generally constant and runs non-stop are known as base load plants. These are of greater capacity. Run of river and storage type power plants are used. As these load plants load factor is very high.

(ii) **Peak Load Plants:** These plants supply power at peak load time i.e., when load is more than average load. Run of river plants with pondage and pumped storage plants are used as peak load plants. They store water during off peak time and supply for peak hours. Load factor is low when compared to base load plants.

7. **Quantity of Water Available or Hydraulic Consideration**

(i) **Run off River Plants**

(a) **Run off River Plants with Pondage:** Pondage refers to collection of water behind dam and increases stream capacity for short periods. It has flexibility to meet hourly demand. Discharge is 3 to 8 times more. Pondage increases stream capacity for short time periods. They can meet peak load demands and used as base load plants.

(b) **Run off River Plants Without Pondage:** Pondage is not provided to increase stream capacity. Dam will be used only to raise hydraulic head and thereby supplying water for some other tasks. In case stream flows are high and if sufficient water remains after supplying for other tasks, it is used for power production through of low levels. Power produced is seasonal. Its utility is very less compared to other plants due to non uniformity of supply.

(ii) **Storage Plants:** These plants have large reservoirs to facilitate storage of water and thus it is independent of seasonal situation. Stream flows are considerably higher than natural flow. This plant can be used as base load as well as peak load plant alternatively. Majority of plants are of these types.

(iii) **Pumped Storage Plants:** Name itself indicates, the water is pumped from tail race to higher level reservoirs in these plants. If water is in adequate for power generation, these are used. These plants are not operated singly but are connected with steam/thermal power plants. Generally the excess of power generated is used to run such plants. Here important point is that generating turbine can also pump the water. Head is generally from 30 m to 300 m from tail race.

(iv) **Tidal Power Plants:** Utilizes sea tidal energy for producing electricity not much capacity available now.

Q73. Write about the importance of small hydro power plants.

Answer :

Importance of Small Hydro Power Plants

The various factors that contribute for the importance of small hydro power plants are as follows.

1. **Environmental Aspects**

As the hydropower plants do not release any heat and pollutants during power generation, these plants are environmental friendly (non-polluting).

2. **Investments and Operating Costs**

Small hydro plants do not require huge machines and skilled operators. Thus, the investment and operating costs are very less.

3. **Continuous Energy**

It is a continuous process of power production, as the resources do not deplete and is always renewed by nature (by hydrological cycle).

4. **Distribution Losses**

In small hydro plants the distribution losses are highly reduced and energy can be supplied to rural consumers. Small hydro plants are ideal decentralized source of power generation.

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Voltage Profile and Utilization Factor

The voltage profile of a small hydro plant can be improved by synchronizing it with the grid. Thus, the utilization factor of the plant is increased. Thus, the plant becomes more economical.

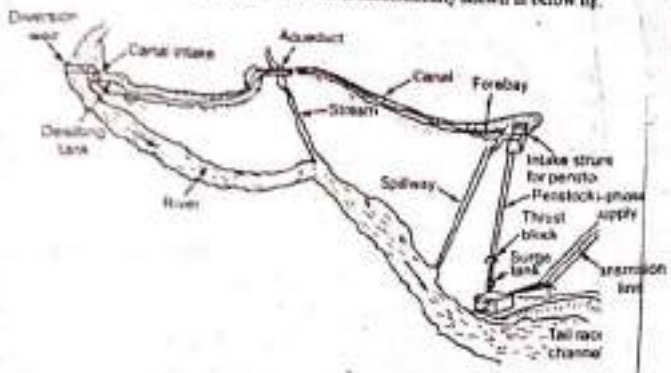
Disturbances by Location

Generally, these plants are located on canals and irrigation systems. Thus, these plants do cause any disturbances to the nearby areas.

Q74. Draw a neat sketch of a typical arrangement of a small hydropower stationd identify the basic components.

Answer :

The typical arrangement of a small hydropower station is schematically shown in below fig.



Figure

The basic and important components of a hydroelectric scheme are as follows.

1. Diversion and intake
2. Desilting chamber
3. Water conductor system
4. Fore bay or balancing reservoir
5. Pen stock
6. Surge tank
7. Power house

Q75. List out the types of turbines for small hydro power plants and explain them. July-21, (EEE), (R16), Q5(b)

Answer :

Power plant that produces power upto 5000 kW are generally called small hydro plant. The various turbines that are used in these power plant are classified according to the arrangement with the generator. They are,

1. Bulb or tubular turbine
2. Tube turbine and
3. Straflo turbine.

1. **Bulb or Tubular Turbine**

In this type, the generator and turbine are either directly connected by a shaft or a gear set. The is kept inside a closed conduit which is water tight casing (bulb). This conduit is placed in the water channel through which water is passed from head race to tail race. A support is provided to the conduit at the centre.

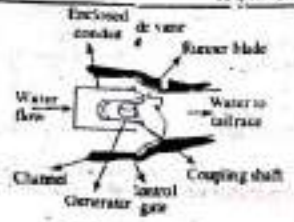


Figure Bulb Turbine

This turbine is a propeller type or Kaplan type and is placedat the downstream side of the channel. Whereas, the generator is plced at the upstream side of the channel. Flow of wer is in axial direction. Power generated is 40 MW200 MW with 3 m-18 m water head availble. Erects and dismantling is easier as are available inpackagenits.

2. **Tube-turbie**

In thirtype,he turbéis placed inside the channel and the generatc is plac outside the channel. Both are connected ung a hornntal or inclined shaft. The flow of water is tial in dection which is directed among thepropellerblades bguide vane and controlled by the control gate. is alscalled as pit type turbine as the generator is pced in pit.

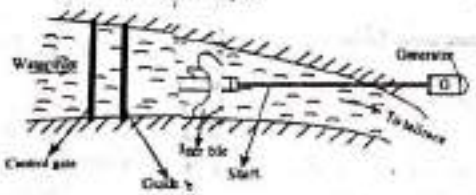


Fig: Tube Turbine

3. **Straflo Turbine**

This is similar to bulb turbine. In this, poles are attached on the iphery of turbine runner. Hence, no separate rotorrequired for generator. In order to avoid water fromring into poles, a specialized seal arrangement is pced. The direction of flow of water is axial and the shis in horizontal direction.

Q76. How primary and secondary power of a hydro power plant is timated?

Answer :

Primary Power

In an hydro electpower plant, the minimum power produced in an entire year known as "Primary Power". It is also known as "firm powe

Secondary Power

The power generated apart from firm power and that to only for a part of year is known as "Secondary power". This secondary power is provided with the help of storage.

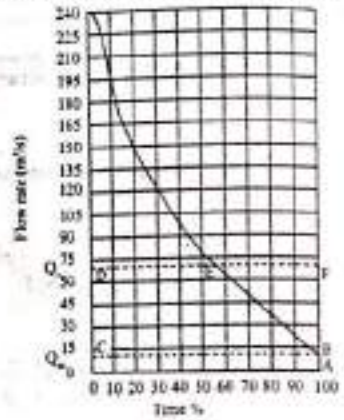


Figure: Flow Duration Curve

The above figure shows the flow duration curve of a hydroelectric power plant. The area under the curve shows the net yield from the stream of water.

"Q_m" be the discharge at 100% time i.e., flow rate all through the year. The power produce is very less and OABC represents the total firm power produced with discharge 'Q_m'.

In order to increase the power, the discharge should be increased to 'Q_s' (represented by demand line DEF) and this can be done only by providing a storage. BFD represents the storage provided to the hydro electric power to add more power to the available firm or primary power.

Thus secondary power is generated and is represented by CBED on the flow duration curve. Hence, primary and secondary power can be estimated through flow duration curve of a particular plant.

Primary power = OABC

Secondary power = CBED.

Q77. What are the advantages and limitations of small scale hydro-electric power generation?

Answer :

Advantages of Small Scale Hydro-electric Power Generation

The advantages of small scale hydroelectric power generation are,

1. Compared to other conventional energy generation machines, the small scale hydro power plants have low gestation period ranging from 8 to 24 months.
2. The cost of operation is low.

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3. The energy sources are non-polluting and no heat is released.
4. There is no consumption of electrical energy by the generator, because the generator uses renewable resources which are always available by the means of hydrologic cycle of environment.
5. Small scale hydroelectric plants a perfect source of decentralised energy generation.
6. When synchronised with utility grids, the voltage profile of the plant is improved.

Limitations of Small Scale Hydro-electric Power Generation

1. The capital cost per kW is high.
2. Maintenance and administrative costs are high.
3. Operation of isolated system is unstable due to low inertia.
4. Relatively low utilisation.
5. Difficulty in site identification, preparation of reports, proper construction planning etc.

Q78. Explain about the economic aspects of mini hydel power plant.

July-19, (R15), Q6(b)

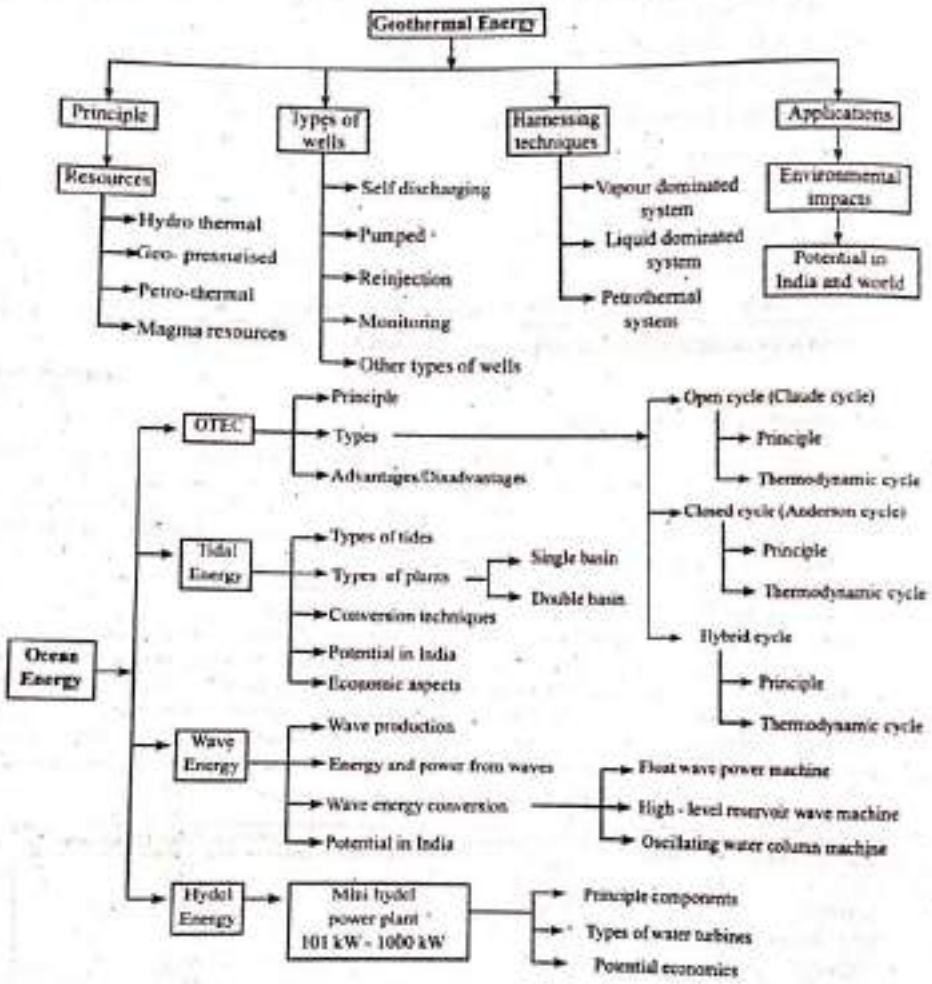
Answer :

Economic aspects of Small/Mini Hydel Power Plant

In India, by employing skills and materials which are available locally, it is possible to design and manufacture components such as floating mills, Himalaya mills and hydraulic rams. Turbines for different small hydro power plants shown in the table below, can be manufactured in Bhopal and Haridwar plants of BHEL (Bharat Heavy Electricals LTD), and Jyoti Ltd., Baroda plant. Purpose of setting up the independent small hydel power plant is an important economic consideration. If an independent plant is installed for power development alone, then construction costs involved will high. Cost of such plants per kW installed will be around Rs. 18000. Therefore, for these plants to be economically successful, they should be setup as multi-purpose plants which can be used for irrigation and other purposes in addition to power generation. Geographical location of the plant also affects the cost of the plant. Head available at top of the hill will be more when compared to that at bottom. Cost of the equipment increases with decrease in the available head. For example, the cost of equipment for one horizontal tubular turbine operating at 3 m head and generating 3.2 kW power may be around Rs. 1.2 lakhs. Thus cost per kW installed will be Rs. 40000. Even though construction costs depends on site of plant installation, it will be 30% of equipment cost. Therefore, total cost per kW installed will be as high as Rs. 52000. But 1 kWh power generation from these plants is less expensive when compared to that of pumped storage hydro power plants. Because the equipment cost, operation cost and maintenance cost are less and cost involved in pumping the water is eliminated. Following table indicates the range of operation of various hydraulic turbines.

Turbine Type	Range of Power Generation (kW)	Range of Operating Head (m)
Pelton	50-6000	100-400
Francis	50-3000	20-200
Turgo impulse	25-3000	50-200
Kaplan	10-6000	2-30
Horizontal tubular	10-6000	2-25

MEMORY MAP



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FREQUENTLY ASKED QUESTIONS AND IMPORTANT QUESTIONS

Q1. Discuss in detail about various methods to harness geothermal energy. 4 TIMES

Ans: Refer Q29. [July-19, (R15), Q9(a) | May-15, (R09), Q6(b) | May-13, (R09), Q6(a) | June-18, (R13), Q7(b)]

Q2. Explain the process of energy conversion from dry rock geothermal resources. 3 TIMES

Ans: Refer Q41. [May-19, (R15), Q3(a) | April-18, (EEE), (R13), Q8(b) | May-17, (ME), (R13), Q8(a)]

Q3. Explain the hybrid cycle operation of OTEC plant with a neat diagram. 3 TIMES

Ans: Refer Q54. [Dec.-20, (R16), Q8 | April-18, (EEE), (R13), Q8(a) | May-17, (ME) (R13), Q9(a)]

Q4. Explain the process of energy conversion from oceans. 3 TIMES

Ans: Refer Q50. [July-21, (ME) (R16), Q9(a) | May-19, (R15), Q5(b) | May-15, (R09), Q7(b)]

Q5. What is the current status of geothermal energy in India? 2 TIMES

Ans: Refer Q8. [June-18, (R13), Q8(a) | April-14, (R09), Q7(b)]

Q6. Explain the principle of energy extraction from OTEC system. 2 TIMES

Ans: Refer Q11. [May-19, (R15), Q1(h) | April-18, (ME), (R13), Q1(k)]

Q7. Show that wave power is directly proportional to the square of amplitude and inversely proportion to the period of wave. 2 TIMES

Ans: Refer Q70. [Sept.-23, (R16), Q8(b) | June-18, (R13), Q9(b)]

Q8. What is hyper-thermal field in geothermal energy and explain? Important Question

Ans: Refer Q4.

Q9. Write a brief note on reinjection wells and monitoring wells. Important Question

Ans: Refer Q35.

Q10. List the various applications of Geothermal energy. Also specify benefits and limitations of geothermal energy storage. Important Question

Ans: Refer Q44.

Q11. What are the limitations of tidal power plant? Important Question

Ans: Refer Q15.

Q12. Give the classification of water turbines. Important Question

Ans: Refer Q22.

Q13. What is the source of tidal energy. What is the minimum tidal range required for the working of a tidal plant? How much is the potential in tides? Important Question

Ans: Refer Q59.

Q14. List the advantages of geothermal energy.

Ans: Refer Q10. Important Question

Q15. Discuss the wave energy conversion machines.

Ans: Refer Q19. Important Question

Q16. Discuss vapour dominated geothermal plant with a diagram.

Ans: Refer Q39. Important Question

Q17. What is geothermal energy and explain the types geo thermal power plants?

Ans: Refer Q43. Important Question

Q18. Discuss the potential of geothermal resource in the world, bringing out the salient points for energy conversion in India.

Ans: Refer Q48. Important Question

Q19. Explain the closed cycle OTEC plant and list out the major problems associated OTEC.

Ans: Refer Q52. Important Question

Q20. Explain different components of Tidal power plants in detail.

Ans: Refer Q60. Important Question

Q21. How does the oscillating wave column convert energy into mechanical from?

Ans: Refer Q67. Important Question

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UNIT 5 DIRECT ENERGY CONVERSION

Syllabus

Direct Energy Conversion: Need for DEC, Carnot cycle, Limitations, Principles of DEC. Thermoelectric generators, Seebeck, Peltier and Joule -Thomson effects, Figure of merit, Materials, Applications.
MHD generators, Principles, Dissociation and ionization, Hall effect, Magnetic flux, MHD accelerator, MHD engine, Power generation systems, Electron gas dynamic convension, Economic aspects. Fuel cells, Principles, Faraday's laws. Thermodynamic aspects, Selection of fuels and operating conditions.

LEARNING OBJECTIVES

On completion of this unit, student should able to understand the following concepts,

- Concept of direct energy conversion
- Seebeck effect, Peltier effect, Joule and Thomson effects.
- MHD generator, MHD accelerator and MHD engine
- Concept of Hall effect
- Fuel cells and selection of fuels

INTRODUCTION

The process of direct conversion of heat energy or chemical energy into electrical energy without any intermediate devices like conventional electric generator is called direct energy conversion.

Some of the direct energy conversion devices are,

I. Fuel cells
II. Solar cells
III. Magneto hydrodynamic power generator device (MHD)
IV. Thermoelectric power generator
V. Thermionic power generator
VI. Ferroelectric power generator.

POINTS TO REMEMBER

- **Direct energy conversion(DEC):** It is the process of direct conversion of heat energy or chemical energy into electrical energy without any intermediate devices like conventional electric generator.
- **Seebeck effect:** Consider two dissimilar metals are joined together in the form a loop such that there are two junctions. When a temperature difference is maintained between these two junctions, an electric current (e.m.f) will flow around the loop. This phenomenon is known as seebeck effect.
- **Peltier effect:** When an electric current flows across an isothermal junction formed because of two dissimilar materials, there is either an evolution or absorption of heat at the junction. This phenomenon is known as the 'peltier effect'.
- **Thomson effect:** When an electric current flows through a material having temperature gradient (i.e., temperature difference between two points), there is an evolution or absorption of heat depending upon the material. This phenomenon is called 'Thomson effect'.
- **Joule effect:** Joule effect states that when a current (I) flows through a resistance R, heat (Q) is generated by the resistance and is equal to I^2R.
- **Thermal Ionization:** At high temperatures, the process of collision of gas molecules at high velocities to form new electrons is known as "Thermal Ionization".
- **Hall effect:** It states that when a piece of semiconductor (conductor) carrying current is placed in a transverse magnetic field, an electric field is generated inside the conductor in a direction normal to both the current and magnetic field.
- **Fuel cell:** It is an electro chemical device in which electrical energy is generated by chemical reaction.

PART-A SHORT QUESTIONS WITH SOLUTIONS

Q1. What is Direct Energy Conversion (DEC)? July-19, (R15), Q1(i)

OR

Write the principle of direct energy conversion and list out various direct energy conversion devices.

Answer :

The process of direct conversion of heat energy or chemical energy into electric energy without any intermediate devices like conventional electric generator is called direct energy conversion.

Some of the direct energy conversion devices are,

1. Fuel cells
2. Solar cells
3. Magneto hydrodynamic power generator device (MHD)
4. Thermoelectric power generator
5. Thermionic power generator
6. Ferroelectric power generator.

Q2. State the limitations of Direct Energy Conversion.

Answer : [May-17, (EEE), (R13), Q1(j)] [Model Paper, Q1(e)]

Limitations of Direct Energy Conversion

1. Solar cells, which used as direct energy conversion systems, are more expensive.
2. Solar cells produces less amount of power.
3. Magnetic hydro dynamic conversion system consumes lot of power to operate the compressor.
4. Magnetic field is to be set up which requires large electromagnets in MHD systems.

Q3. List out the limitations of Carnot cycle. April-18, (ME), (R13), Q1(i)

OR

What are the Limitations of Carnot cycle in DEC? May-17, (ME), (R13), Q1(i)

OR

State the limitations of Carnot cycle.

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Answer :

Limitations of Carnot Cycle

1. The steam produced during the isentropic process is difficult to compress till the saturated state.
2. For the proper steam expansion to be obtained, the quality of the condensate leaving the condenser is difficult to control.
3. If the cycle is operated for cooling down the steam, the temperature has to be decreased which results in decreases efficiency.
4. The cycle cannot be used practically, as superheated steam is to be supplied at constant temperature, which is not possible.

Q4. Explain thermoelectric phenomenon.

Answer : May-19, (R15), Q1(i)

The thermoelectric effect is the phenomenon of the direct conversion of temperature differences to electric voltage or vice versa.

Electrically conductive materials exhibit following three types of thermoelectric phenomenon,

1. Seebeck effect
2. Pelter effect
3. Thomson effect

Q5. Write short notes on criterion for selection of materials for thermoelectric generators.

Answer :

The following points should be considered while selecting the thermoelectric materials.

1. The semiconductor should have component thermal conductivity as low as possible. The value of k can be decreased by introducing appropriate impurities.
2. The mobility of current carriers such as electrons or holes should be as high as possible, and should not be reduced with the introduction of impurities.
3. In thermoelectric generator, one arm should be of a purely hole type and the other is of purely electronic semiconductor. Thus, the semiconductor with low ionisation energy and narrow forbidden band should be selected.
4. The arms of the thermoelement are made with a variable impurity content or constructed from several parts. The impurity concentration in the low temperature zone should be lower than the high temperature zone.
5. The material should have high strength, elasticity so that it will not crack due to thermal stresses. It should also have high corrosion resistance.
6. The bridge material should posses high thermal and electrical conductivity and it should with stand the thermal stresses.

Q6. Explain the principle of Thermionic generator.

Answer : April-18, (R13), (EEE), Q1(j)

Thermionic generator works on the principle of thermionic emission, which states that if any metal is heated, it emits electrons.

Explanation : When the thermal energy is supplied to any solid substance, the amplitude of lattice vibrations of the solid increases. As a result, the collisions with free electrons that occur within the solid become more energetic. Thus, the electrons receive sufficient energy to escape from the metal solid surface. The energy required to extract an electron from the metal is known as work function.

Q7. What is the principle of operation of MHD generator?

Answer : [July-19, (R15), Q1(j)] [Model Paper, Q1(j)]

The principle of MHD power generation is the on Faraday's law of electromagnetic induction. It states that, when an electric conductor passes across a magnetic field a voltage is induced in the conductor which produces an electric current. The MHD power generator uses of a gaseous conductor, i.e., an ionised gas, instead of solid conductor. The ionised gas is passed through a powerful magnetic field at a high velocity, which generates the current.

Q8. What are the factors to be considered for selecting materials for MHD generators?

Answer :

The factors that are considered while selecting the materials for MHD generators are as follows,

1. Resistance to thermal shocks
2. Electrical conductivity of materials
3. Ability to resist corrosion
4. Resistance to erosion
5. Chemical stability
6. Melting point of materials
7. Material density.

Q9. What is the principle of energy conversion in fuel cell? May-19, (R15), Q1(j)

OR

Write the principle of fuel cells?

Answer : April-18, (ME), (R13), Q1(j)

Principle of Fuel Cells

The fuel cells convert the chemical energy of fuel directly into electrical energy by an electrochemical process.

Q10. List different types of fuels used in fuel cell and state the properties, that are considered in selection of fuel cells.

Answer :

Types of Fuels

The different types of fuels used in fuel cells are listed as follows.

(i) Hydrogen

(ii) Hydrocarbon fuels

(iii) Fossil fuel

(iv) Alcohol fuel

(v) Hydrazine fuel.

Properties to be Considered in Selection of Fuel Cells

The properties that are considered in selecting the fuel cells are.

(i) The energy conversion efficiency should be high

(ii) It should not cause chemical pollution

(iii) It must possess flexibility to work with any fuel.

(iv) It should be highly responsive to loads and compatible with cogeneration systems.

Q11. Differentiate Seebeck and peltier effect.

Answer : June-18, (R11), Q1(j)

Seebeck Effect

For answer refer Unit-V, Q18, Topic: Seebeck Effect

Peltier Effect

For answer refer Unit-V, Q18, Topic: Peltier Effect

Q12. Explain the concept of seebeck effect.

Answer : May-17, (ME), (R13), Q1(j)

For answer refer Unit-V, Q18, Topic: Seebeck Effect.

Q13. Explain the concept of DEC and Seebeck effect.

Answer : April-18, (EEE), (R13), Q1(i)

Concept of DEC

For answer refer Unit-V, Q1.

Seebeck Effect

For answer refer Unit-V, Q18, Topic : Seebeck Effect.

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PART-B ESSAY QUESTIONS WITH SOLUTNS

5.1 Need for DEC, Carnot Cycle, Limitations and Principles of DEC, Thermoelectric Generators, Seebeck, Peltier, Joule and Thomson Effects, Figure of Merit, Matals, Applications

Q14. Explain the principle of direct energy conversion with examples.

Answer : [May-18, (R13)(a) | Model Paper, Q10(a)]

Principle of DEC

According to the principle of direct energy conversion, the transformation of one type of energy (all naturally available energies such as solar energy, wind energy, etc.) to another form of energy such as electricity occurs but an intermediate stage (i.e., conversion of energy into mechanical energy).

The use of direct energy conversion devices has been limited to small scale and special pur applications, since the voltage output of these devices is small.

Examples

1. **Fuel Cell**

   It is a direct electric conversion device, which converts the chemical energy of a conventional fuel directly into electric energy.

2. **Solar cell**

   Solar cells convert the sunlight into electricity by using the principle of photovoltaic effect.

3. **Thermoelectric Generators**

   These devices convert the heat energy directly into the electricity.

Q15. Discuss the need and principle for DEC.

Answer : y-17, (EEE), (R13), Q10(b)

Need for DEC

1. There is no intermediate conversion of energy such as mechanical energy and then to the electy.
2. Energy losses are significantly less during conversion process.
3. It is more efficient process.
4. It is more economical compared to other conversion techniques.

Principle of DEC

For answer refer Unit-V, Q14, Topic : Principle of DEC.

Q16. What are the two statements known as the carnot principle

Answer : y-17, (EEE), R13, Q10(a)

1st Carnot Principle

It states that "the efficiency of reversible heat engine is always higher than the irreversible engine, when both are operating between same thermal reservoirs".

2nd Carnot Principle

It states that "all reversible heat engines operating between the same thermal reservoirs will have same efficiency".

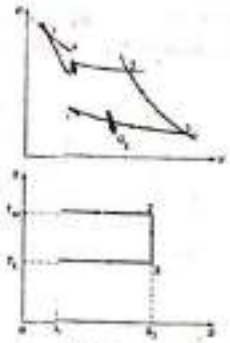
Q17. Explain the carnot cycle

Answer : June-18, (R13), Q10(a)

The Carnot cycle was proposed by a french engineer, Sadi Carnot in 1824. This cycle is also called as reversible cycle, and it is comprises of four reversible processes. They are,

1. Reversible isothermal expansion (Process 1-2)
2. Reversible adiabatic expansion (Process 2-3)
3. Reversible isothermal compression (Process 3 – 4)
4. Reversible adiabatic compression (Process 4 – 1)

The above process be shown in thermodynamic cycle on PV and Ts diagrams shown in below figure.



Figure

Working Principle of Carnot Cycle Engine

1. **Reversible Isothermal Expansion (Process 1 – 2)**

   In this process heat is added to the working medium at constant temperature T_H, and the working medium (gas) expands slowly from state 1 to state 2 isothermally.

2. **Reversible Adiabatic Expansion (Process 2 -3)**

   In this process gas expands gradually in adiabatic manner, and simultaneously does the work on the surroundings the temperature reduces to T_L.

3. **Reversible Isothermal Compression (Process 3 – 4)**

   During this process, the gas is compressed by an external force, and the temperature of the gas is maintained at constant value rejecting the heat continuously to the heat sink.

4. **Reversible Adiabatic Compression (Process 4-1)**

   In this process gas is compressed adiabatically from state 4 to state 1.

The efficiency of the Carnot cycle is given by,

$$\eta_{th} = \frac{\text{workdone}}{\text{heat supplied}} = \frac{W_{net}}{Q_H}$$

$$\eta_{th} = 1 - \frac{T_L}{T_H}$$

Q18. Elaborate seebeck, peltier, Joule and Thomson effects with the practical applications.

Answer :

1. **Seebeck Effect**

   Consider two dissimilar metals are joined together in the form a loop such that there are two junctions. When a temperature difference is maintained between these two junctions, electric current (e.m.f) will flow around the loop. This phenomenon is known as seebeck effect.

   The principle of seebeck effect is illustrated in below figure.

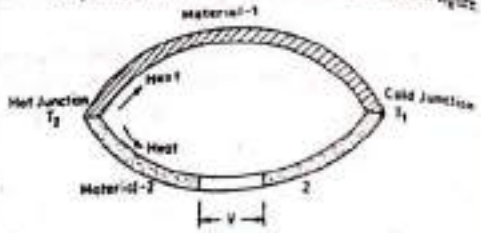


Figure (1)

The magnitude of current depends on the materials used and the temperature difference between the junctions (i.e., $\Delta T = T_2 - T_1$).

The magnitude of e.m.f is given by,

$$V(\text{or})E = \alpha_s \Delta T$$

Where,

α_s – seebeck coefficient

ΔT – Temperature difference between hot and cold junctions.

Applications

Seebeck effect is used in 'thermocouples' to measure the temperature, and in thermoelectric generation for power generation.

2. **Peltier Effect**

   When an electric current flows across an isothermal junction formed because of two dissimilar materials, there is either an evolution or absorption of heat at the junction. This phenomenon is known as the 'peltier effect'.

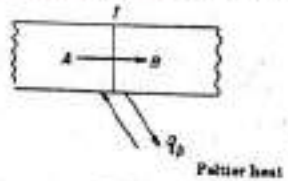


Figure (2)

Since the peltier effect is a reversible effect, the heat is evolved when current flows in one direction and the same amount of heat is absorbed at the junction if the current flows in reverse direction.

Peltier Coefficient (α_{A-B}) : It is defined as the heat evolved or absorbed at the junction per unit current flow per unit time.

i.e., $\alpha_{A-B} = \alpha_A - \alpha_B = \frac{Q_p}{I}$

Then, $Q_p = \alpha_{A-B} \times I$

Where,

I – Peltier heat per unit time

Q_p – Peltier heat

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Applications

Peltier effect is used in cooling and heating applications such refrigeration and air conditioning, IC cooling, etc.

3. **Joule Effect**

   Joule effect states that when a current (I) flows through a resistance R, heat (Q) is generated by the resistance and is equal to I^2R.

   i.e., Joulean heat $Q = I^2R$

The conversion of electric energy into heat is irreversible.

Applications of Joule Effect

Applications of Joule effect are found in electrical devices such as electric iron, electric toaster, and electric heating, etc.

4. **Thomson Effect**

   When an electric current flows through a material having temperature gradient (i.e., temperature difference between two points), there is an evolution or absorption of heat depending upon the material. This phenomenon is called 'Thomson effect'. The Thomson effect is schematically shown in below figure.

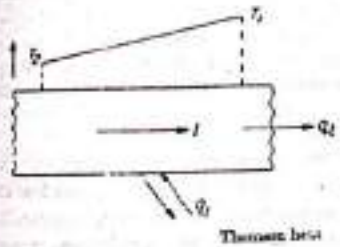


Figure (3)

The Thomson heat is reversible, since the direction of heat transfer can be reversed with out change in magnitude by reversing the direction of current flow.

Thomson Coefficient (σ)

It is defined as Thomson heat absorbed or evolved per unit time per unit electric current and per unit temperature gradient.

$$\text{i.e., } \sigma = \frac{\frac{dQ_T}{dt}}{\frac{dT}{dx}}$$

Where,

$\frac{dQ_T}{dx}$ – Heat interchange per unit time per unit length of conductor

$\frac{dT}{dx}$ – Temperature gradient.

Therefore, the Thomson heat per unit time is given by

$$\frac{dQ_T}{dx} = \sigma I \frac{dT}{dx}$$

The Seebeck, Peltier and Thomson effects are more commonly observed in semiconductors compared to metals.

Applications of Thomson Effect

Applications of Thomson effect found semiconductors.

Q19. Explain (i) Seebeck (ii) Peltier and (iii) Joule Thomson effects.

Answer : Apr-13, (ME), (R13), Q10(a)

For answer refer Unit-V, Q18, (Excluding applications)

Q20. Explain the concept of joule Thompson effect and its applications.

Answer : May-17, (ME), (R13), Q10(a)

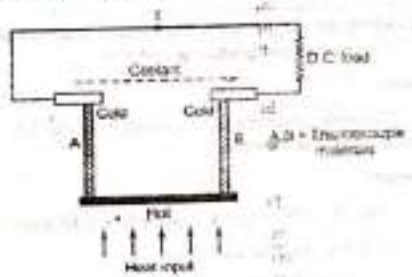
For answer refer Unit-V, Q18, Topics: Joule Effect and Thomson Effect.

Q21. Describe briefly the working of a thermoelectric generator.

Answer : May-15, (R15), Q10(b)

Thermoelectric generator is a device that converts the heat energy directly into electrical energy by using the 'seebeck effect'. It is very simple DEC device but the efficiency is very low of the order of 1% to 5%. The efficiency of the thermoelectric generator depends upon the temperatures of the hot and cold junctions.

A simple arrangement of thermoelectric power generator is shown in below figure.



Figure

As shown in figure, the thermocouple materials A and B are joined at the hot end, and the other ends are kept cold. Then an electric current or electromotive force is generated due to the between the cold ends due to the temperature difference. This direct current (DC current) will flows in a circuit or through an external load connected between these ends. The flow of current will be continuous until the heat is supplied at the hot junction (generally, solar energy is supplied) and removed from the cold ends by using cold water. The voltage and power output of any thermocouple can be increased by increasing the temperature difference between the hot and cold ends.

The net useful power output of the thermoelectric power generator is given by,

$$W = I^2 R$$

Where,

I – Current in amp (A)

R – Extremely load resistance (Ω)

The current in the circuit is given by,

$$I = \frac{\alpha \Delta T}{(R_i + R)}$$

Where,

α – Seeback coefficient

ΔT – Temperature difference between hot and cold junctions

R_i – Internal resistance of thermoelectric generator

In practical thermoelectric converter, number of thermocouples are connected in series to increase both voltage and power output.

Q22. Explain the principles of Direct Energy Conversion and with the help of line diagram, explain the working details of thermoelectric generator.

Answer : April-18, (EEE), (R13), Q10

Principle of Direct Energy Conversion

For answer refer Unit-V, Q14, Topic: Principle of DEC.

Working of Thermoelectric Generator

For answer refer Unit-V, Q21.

Q23. Write the advantages and disadvantages of thermoelectric power generator.

Answer :

The thermoelectric power generator has the following advantages and disadvantages.

Advantages

1. These are very simple in construction and compact.
2. Highly reliable and durable.
3. Since there are no moving parts used, it is free form noise.
4. It requires minimum maintenance.
5. Since it is portable, can be used for remote and space applications.
6. It uses low grade thermal energy.

Disadvantages

1. The output is low
2. The efficiency is low
3. The cost is high

Q24. Describe the operation of a thermionic converter.

Answer : Model Paper, Q11(a)

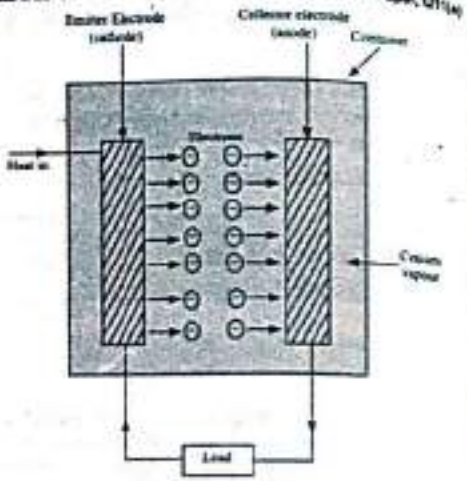


Figure : Thermionic Converter

In a thermionic convertor, electrons will act as a working fluid instead of vapour or gas. It works on the principle of "thermionic emission effect", i.e., emission of electrons from the heated metal surface. The energy required for the emission of election from a metal is known as "work function" which depends on the nature of metals and its surface conditions.

Working

Thermionic converter consists of two electrodes, one is called emitter electrode made of tungsten and the other is collector electrode made of cesium coated tungsten. The emitter electrode is maintained at higher temperature. Hence, its work function value is high. Whereas the work function value of collector electrode is less. These two electrodes are placed in a container which consists of ionised gas or cesium vapour to avoid or reduce "space charge". On heating the emitter electrode, electrons are emitted and move towards collector electrode, which becomes negatively charged. This movement of electrons will lead to development of a electromotive force (voltage) between the two electrodes. Hence, direct electrode current flows through the external circuit.

In thermionic converter, more power can be obtained by.

1. Maintaining the emitter electrode's temperature of to 1000°C.
2. By coating the collector electrode with solid cesium. This will reduce the work function of the electrode and increases the output power.

Efficiency of 40% can be obtained with higher temperature of the emitter electrode.

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Q25. Explain briefly about the 'figure of merit'

Answer :

The 'figure of merit' is an index used in rating thermoelectric converters. It is denoted by 'Z'.

For a single material,

$$Z = \left[\frac{\alpha_{24} - \alpha_{14}}{\sqrt{\rho_A k_A} + \sqrt{\rho_B k_B}}\right]^2$$

The 'figure of merit' depends on the thermoelectric material properties. The material having large see back coefficient, small thermal conductivity and small electrical resistivity, results in higher value of 'Z'.

The quality of the thermocouple increases with the value of Z.

Q26. List various thermoelectric materials used.

Answer :

The following materials are widely used in thermoelectric materials.

	Material	Formula	Figure of merit, Z(°K⁻¹)
1.	Lead telluride	PbTe	1.5×10^{-3}
2.	Bismuth telluride (doped with Sb or Se)	Bi_2Te_3	4×10^{-3}
3.	Germanium telluride (with bismuth)	GeTe	1.5×10^{-3}
4.	Cesium sulphide	CeS	1.0×10^{-3}
5.	Zinc antimonide (doped with silver)	Zn Sb	1.5×10^{-3}

Q27. Explain the heating and cooling applications of a thermoelectric system comment on the materials used for low and high temperature applications.

Answer : June-15, (R13), Q8

Thermoelectric coolers and heaters are some times called as thermoelectric modules. These are solid state devices (i.e., no moving parts are present) that convert electrical energy into heat energy (i.e., temperature gradient) based on the "peltier effect".

Cooling and heating applications of a thermoelectric system are as follows.

1. **Refrigeration :**

   Used in small refrigerators and mini in-vehicle refrigerators.

2. **Air Conditioning**

   Used in air conditioning systems for zonal climate control, i.e., controlling the climate where it is needed, thus, the operating cost can be reduced.

3. **Thermal Comfort**

   Thermoelectric systems are used for providing thermal comfort in following purposes.

   (i) Heated and cooled mattresses
   (ii) Heated and cooled vehicle seats
   (iii) Heated and cooled office chairs

Thermal Convenience

Used for beverage heating and cooling, and also used in wine bottle coolers.

Electronics Cooling

Thermoelectric system are used in following electronic cooling applications.

(i) Electronics and CPU cooling.
(ii) Kiosk cooling
(iii) Telecom cooling devices
(iv) Battery thermal management.

Thermoelectric Materials

The thermoelectric materials are mainly three types based on their working temperatures.

1. **Bismuth Telluride (Bi_2Te_3) Alloy :** This material is a type of semiconductor. It is best suited for thermoelectric refrigeration with working temperatures less than 450°C.

   It has high electricity conductivity, but the heat transfer capability is low.

2. **Lead Telluride (PbTe) Alloy :** This material is extremely toxic, generally causes water pollution, and also damages respiratory organs, skin and stomach in humans. It has a melting point of 905°C. It is used for thermoelectric generator and it is suitable for working temperatures around 1000°C.

3. **Silicon – Germanium Alloy :** This material is a type of semiconductor, mostly used for thermoelectric generator. The optimum working temperature is about 1300°C.

Q28. Explain about the applications of thermoelectric generators.

Answer : July-19, (R15), Q11(a)

The thermoelectric generators have following applications.

1. **Nuclear Reactor With Thermoelectric Fuel Elements**

   The thermoelectric generators can be [illegible] in the fuel elements of the nuclear reactor as shown in below figure.

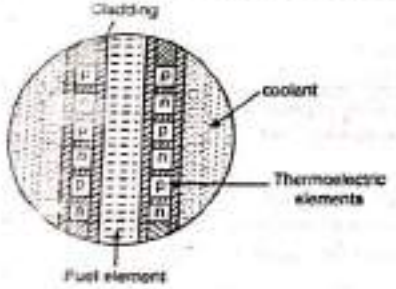

Figure (1)

With the use of thermoelectric generator, large power outputs can be obtained in nuclear reactors.

2. **Combined Thermoelectric And Steam Power Plant**

   The thermoelectric generator can be [illegible] ing plant to a steam power plant, which increases the source temperature to a great extent. Therefore, the overall efficiency of the combined plant will increase. The schematic diagram of the combined thermoelectric and steam power plant is shown in below figure.

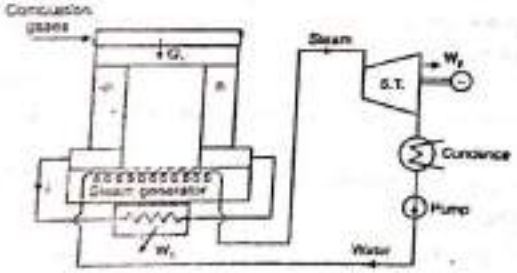

Figure (2)

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Thermoelectric Waste Heat Stack

Thermoelectric generators can be used to produce electricity by using the waste heat from gas turbines, diesel engines and the exhaust (or) stack gases. The schematic diagram of the use of thermoelectric generators is shown in below figure.

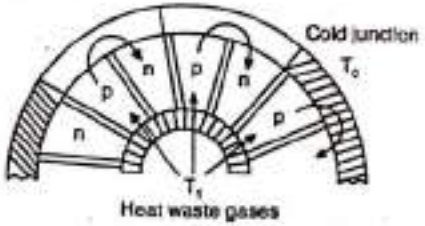


Figure (3)

As shown in figure, the metal stack consists of a series of rings made of two different materials connected at the inner and outer annular edges alternately.

2. **Decay Heat of Radioactive Isotopes**

   Small thermoelectric generators are used for converting the decay heat of radioactive isotopes into electricity. Radioisotope thermoelectric generators (RTGs) are used in space applications for power generation in satellites, spacecrafts, etc.

3. **Electricity From Solar Energy**

   Thermoelectric generators are used along with the solar collectors to generate electricity from the solar energy.

5.2 MHD Generators, Principles, Dissociation and Ionization, Hall Effect, Magnetic Flux, MHD Accelerator, MHD Engine, Power Generation Systems, Electron Gas Dynamic Conversion, Economic Aspects

Q29. Explain the working details of MHD accelerator May-17, (R13), Q10(b)

OR

Explain the principle of MHD power generation.

[May-13, (R09), Q5(a) / Model Paper, Q7(a)]

Answer :

The principle of MHD power generation is the Faraday's law of electromagnetic induction. It states that, when an electric conductor passes across a magnetic field a voltage is induced in the conductor which produces an electric current. The MHD power generator uses a gaseous conductor i.e., an ionised gas instead of solid conductor. The ionised gas is passed through a powerful magnetic field at a high velocity, which generates the current. This current is extracted by mounting the electrodes that are placed in an appropriate position in the stream of ionised gas. The MHD generator produces d.c. power directly. The arrangement and principle of MHD generator is schematically shown in below figure.

Consider an electric conductor, that is moving through the magnetic field. Then, the conductor experiences a retarding force, and an electric field is induced which produces current according to the Faraday's law of electromagnetic induction.

The induced emf is given by,

E_{ind} = Velocity of conductor × Magnetic field intensity

$$\vec{E}_{ind} = \vec{u} \times \vec{B}$$

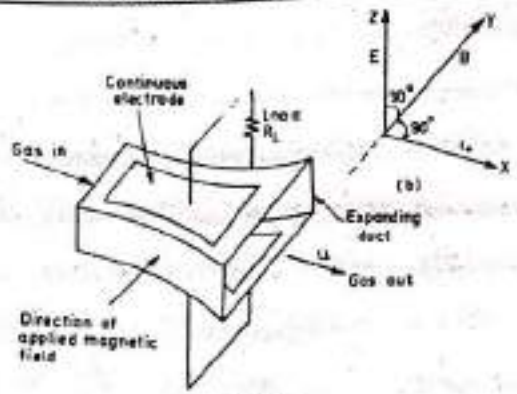
The current density is given by,

J = Electrical conductivity × emf induced

$$\vec{J}_{ind} = \vec{\sigma} \times \vec{E}_{ind}$$

The retarding force experienced by the conductor is the Lorentz force, and is given by,

$$\vec{F}_{ind} = \vec{J}_{ind} \times \vec{B}$$



Figure

Q30. What is the principle of MHD power generation and discuss about the main parts of an MHD generator?

Answer : April-18, (ME), (R13), Q10(b)

Principle of MHD Power Generation

For answer refer Unit-V, Q29.

Parts of MHD Generator

The main parts of the MHD generator are as follows,

1. **MHD Duct**

   The high temperature ionised gas flows through this duct at a very high velocity.

2. **Magnetic Field**

   The magnetic filed is produced by some appropriate coils, and its direction is at right angles to the gas flow.

3. **Electrodes**

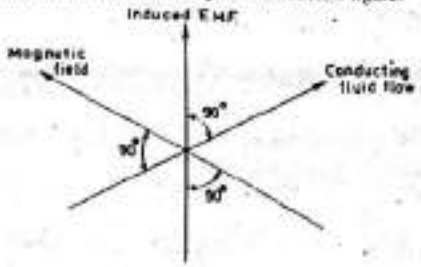
   The electrodes are placed at suitable locations to carry the current to external loads in the Faraday and Hall configurations.

Q31. Explain the principle of magneto hydrodynamic conversion.

Answer :

Magneto hydrodynamic conversion (MHD) is an energy conversion technique in which, the kinetic energy of an electrically conducting fluid (a gas or a gas combination) when flows through a stationary magnetic field is directly converted into electrical energy.

The basics principle of MHD conversion is schematically shown in below figure.



Figure

As shown in the figure, when the direction of flow of the electrically conducting fluid is perpendicular to the direction of magnetic field, an electromotive force or electric voltage is induced in the direction perpendicular to both conducting fluid flow and magnetic field directions.

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Q32. Explain about (i) MHD accelerator (ii) MHD engine.

Answer : July-19, (R13), Q10(b)

(i) MHD Accelerator

For answer refer Unit-V, Q29.

(ii) MHD Engine

MHD engine is proposed as a single flow path alternative to current turboramjet engines used in space applications.

Consider a hypersonic airbreathing engine of a ramjet or scramjet type that is augmented with an MHD energy management system. This engine uses the MHD bypass energy concept. The various components of the engine is shown in below figure.

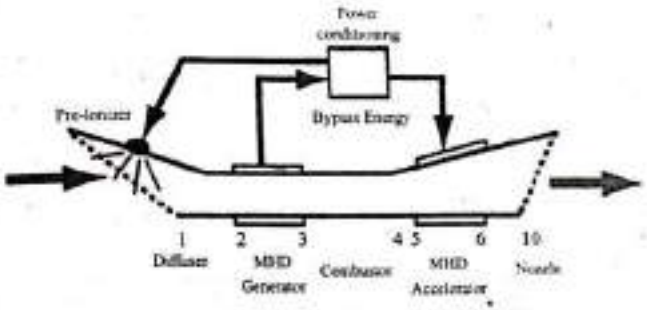

Figure (1) : Hypersonic Air-breathing Engine with MHD Energy Bypass System

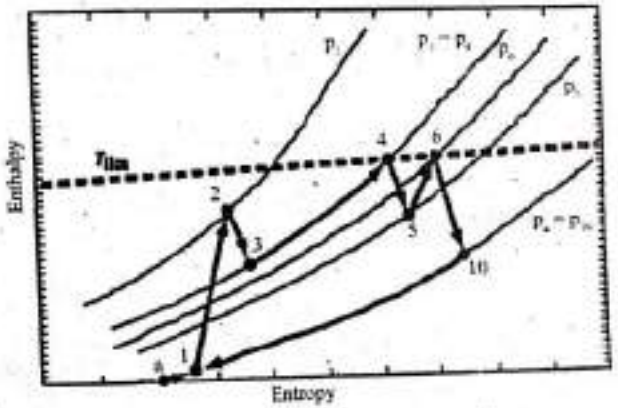

Figure (2) : Ts Diagram

As shown in the figure, the description of each process is as follows.

Process (a - 1) : Air pre-ionisation and heat addition

Process (1 - 2) : Adiabatic compression and flow deceleration

Process (2 - 3) : MHD conversion of total enthalpy to electrical power and deceleration of the flow.

Process (3 - 4) : Constant static pressure and frictionless heat addition.

Process (4 - 5) : Adiabatic expansion to maintain the temperature inside the accelerator in design limits.

Process (5 - 6) : MHD conversion of electrical power to total flow enthalpy and acceleration of the flow.

Process (6 - 10) : Adiabatic expansion and acceleration of the exhaust flow.

The MHD engines are capable of extending the operating range of turbojets to the Mach number 7 for sustained hypersonic flight.

Q33. Explain the principle of dissociation and ionization with respect to MHD.

Answer :

April-13, (ME), (R13), Q1(b)

Ionization is the process in which the electrons are removed from an atom. This process is employed to increase the conductivity of the working fluid used in MHD systems to a required level.

The electrical conduction occurs due to the movement of the free electrons and positive ions under the effect of a magnetic field. The following are various ionization methods.

1. Thermal ionization
2. Magnetically induced ionization
3. Radio frequency wave induced ionization
4. Photo ionization
5. Radioactivity
6. Radioactivity
7. Flames

However, only first three methods are used in practice.

1. Thermal Ionisation

In this method of ionisation, sufficient amount of thermal energy is supplied to the gas to achieve ionisation. With the increase of temperature of the gas, the kinetic energy of its constituents also increases. When the temperature is increased to a sufficiently high value, then the electron gets the ability to ionise a molecule with which it collides. These electron molecule collisions produce more number of electrons. This phenomenon is called thermal ionisation.

2. Magnetically Induced Ionisation

In this method, a d.c. voltage is applied across a gas at reduced pressure to create an electric field. This electric field supplies energy to the electrons.

3. Radio Frequency Wave Induced Ionisation

This method can produce a low amount of ionisation in the gas. The amount of ionisation produce by this method is not sufficient enough for MHD generation.

Q34. What is Hall effect? Explain its significance.

Answer :

Hall Effect

When a current carrying semiconductor bar is kept in a transverse magnetic field, an electric field is produced within the semiconductor. The direction of generated electric field is perpendicular to both the current and applied magnetic field. This process is referred to as Hall effect. Due to the generated electric field, a voltage is developed across the surfaces of semiconductor bar known as Hall voltage.

$$R_H = \frac{1}{ne} = \frac{-1}{qn} \quad [\because \sigma = -ne]$$

Significance

1. Determination of Type of Semiconductor

The sign of the Hall coefficient depends on the type of semiconductor placed in the transverse magnetic field. Hall coefficient is negative for an n-type semiconductor and positive for a p-type semiconductor. Therefore, the sign of the Hall coefficient is used to determine whether a given semiconductor is n or p-type.

2. Calculation of Carrier Concentration

Concentration of the carrier inside the semiconductor bar placed in the magnetic field can be determined using the expression

$$n = \frac{1}{e} R_H = \frac{1}{e} \frac{I_x b}{I_x B}$$

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Where,

B – Magnetic flux density in Wb/m²

I_x – Current flowing through the semiconductor bar

b – Width of the bar

V_H – Hall voltage

The Hall voltage 'V_H' is measured by placing two probes at the centers of the top and bottom surfaces of the semiconductor bar.

Determination of Mobility

Assuming that the flow of current in the n-type semi conductor bar placed in the magnetic field is only due to majority carrier, that is electrons.

$$\sigma = ne\mu_n$$

$$\mu_n = \frac{\sigma}{ne} = \sigma R_H$$

Since, $R_H = \frac{V_H b}{I_x B}$

$$\mu_n = \sigma\left(\frac{V_H b}{I_x B}\right)$$

If σ is known the mobility μ_n can be determined. Similarly, μ_p is determined by placing a P-type semiconductor bar in the magnetic field.

Hall Effect Multiplier

If the magnetic field 'B' (in which the semiconductor bar is placed) is produced by an air core coil carrying a current I' through it, then B is proportional to I'. The Hall voltage which is a product of B and I_x (I is the current flowing through the bar) will now be a product of I' and I. This forms a basis of the multiplier.

Determination of Magnetic Flux Density

The Hall voltage V_H is directly proportional to magnetic flux density, of a semiconductor. Hence, B is calculated using the formula,

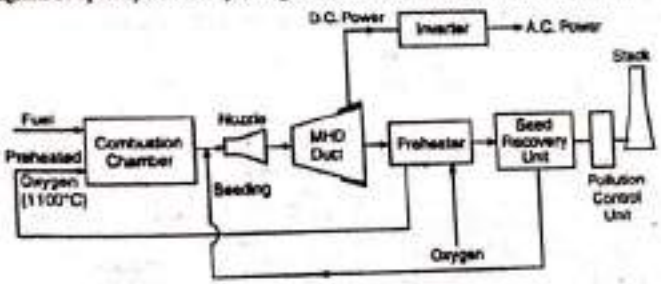
$$B = \frac{V_H b}{I_x R_H}$$

Q35. Explain the working of open cycle MHD system generation and its advantages and limitations.

Answer :

April-15, (EEE), (R13), Q11

The schematic diagram of open cycle MHD power generation system is shown in below figure.



Figure

This system consists of the following main components.

1. Combustion Chamber

The fuels like coal, oil or natural gas are burnt with the preheated or hot compressed air in the combustion chamber. The compressed air must be preheated to at least 1100°C before supplying to the combustor. The high temperature and high pressure gases are produced due to the combustion process. Then the seeding material (cesium or potassium) is injected and mixed with the not gases to increase the electrical conductivity of the gases. Potassium carbonate is the most commonly used seeding material. The not pressurised gases, known as working fluid leaves the combustor and flows through the convergent- divergent nozzle. Thus, the working fluid coming out from the nozzle enters the MHD generator at a high speed.

2. **MHD Generator**

The MHD generator is a divergent channel or duct which is made of a heat resistant alloy such as Inconel, with external water cooling. The direction of magnetic field is perpendicular to the direction of the motion of hot gases. A number of electrode pairs are placed in the duct at suitable location to conduct the electricity produced to the external load. The d.c power is converted into a.c power by using an inverter.

3. **Preheater**

The temperature of the hot gases falls to 1900°C after producing electricity. These gases enters the gas preheater, where oxygen or oxygen enriched air or compressed air is heated to a temperature of 1100°C. This preheated air is used to produce the working fluid at a temperature range of 2300°C to 2700°C to 2700°C in the combustion chamber.

4. **Seed Recovery Unit**

In seed recovery unit, the seeding material is recovered for reusing purpose. Due to the presence of sulphur in the fuel, the potassium carbonate is converted into potassium sulphate. During recovery process, the potassium sulphate is converted back to potassium carbonate by desulfurization method.

5. **Hot Gases**

The gas gases from the seed recovery unit are passed through pollution control device to remove sulphur and nitrogen oxides before releasing into the atmosphere through the chimney.

Advantages and Limitations of MHD System Generation

For answer refer Unit-V, Q38.

Q36. Describe MHD closed cycle system, with its advantages and disadvantages. May-18, (R15), Q10(a)

OR

With the help of a diagram explain the operation of closed cycle MHD generating system.

Answer : June-18, (R13), Q10(b)

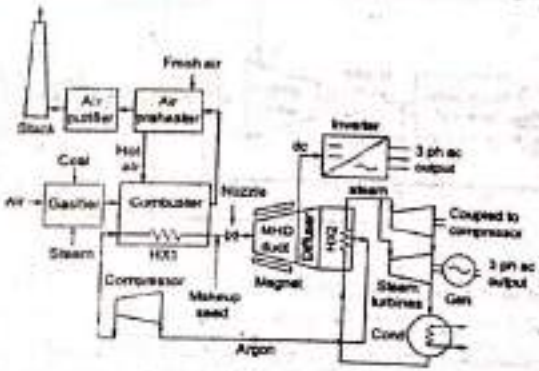
The closed cycle MHD power generation system are of two types.

1. Seeded inert gas system
2. Liquid metal systems

Seeded Inert Gas System

The seeded inert gas system works on Brayton cycle with inert carrier gas (either argon or helium). Similar to open cycle MHD systems the electrical conductivity is maintained in the working fluid by the ionisation of a seed material.

The schematic diagram of a closed cycle seeded inert gas system is shown in below figure.



Figure

This system consists of three loops. They are.

1. **Combustion Loop**

It is an open loop, in which the coal is gasified and burns in the combustor. The flue gases are made to pass through the primary heat exchanger (H 1), air preheater and air purifier and then released into the atmosphere.

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Argon Loop or MHD Loop

In MHD loop, the seeded inert gas, either argon or helium is compressed in a compressor and it is heated by passing through the primary heat exchanger. Then, a small amount of seed material is added to compensate the loss of seed material through leakages. The cesium metal is used as seed material in this system. It is expensive than potassium, but it provide sufficient conductivity at a relatively lower temperature of about 1900°C. Due to lower operating temperatures, this system allows the use of variety of materials for different equipment. But the efficiency of the cycle reduces due to lower operating temperature. The d.c electricity available form the MHD generator is converted to a.c electricity by using an inverter, and then fed into the grid.

Steam Loop

This loop is used for further recovery of the heat of working fluid and converting this heat into electrical energy through a waste heat boiler known as secondary heat exchanger, turbine and generator. Some amount of this electrical energy used in in the argon cycle compressor through a steam turbine.

Advantages and Disadvantages of MHD system

For answer refer Unit-V, Q38.

Q37. Discuss briefly about liquid metal MHD system with a neat sketch.

Answer :

In this system, a liquid metal provides the electrical conductivity, and the carrier gases are inert gases like argon and helium. The combustion chamber is provided with an heat exchanger internally, which is used to pressurize and heat the carrier gas. The heated and pressurized gas is incorporated into the liquid metal, usually hot sodium to form the working fluid. The working fluid is passed into the MHD generator through a nozzle. Then the carrier gas supplies the high directed velocity of the electrical conductor (i.e., the liquid metal).

After passing through the generator, the liquid metal is separated from the carrier gas. The remaining heat in the gas is used to the water in the secondary heat exchanger to obtain steam for operating the turbine generator. The schematic diagram of closed cycle liquid metal system is shown in below figure. Finally, the gas is cooled, compressed and returned to the combustion chamber for reheating and mixing with the recovered liquid metal.

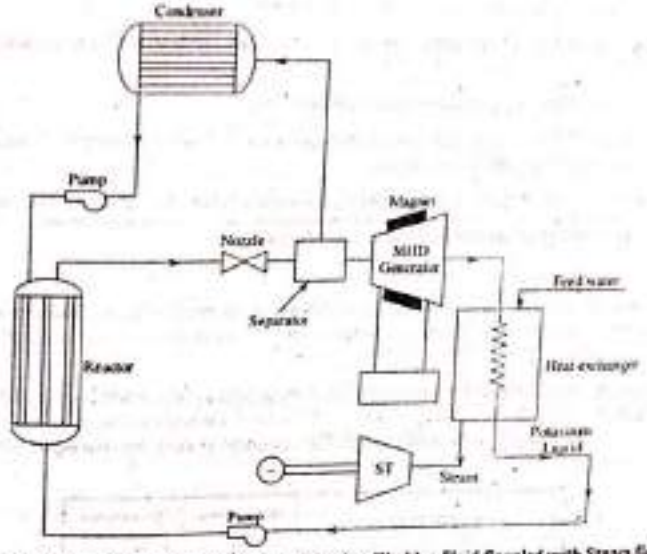

Figure: Closed Cycle MHD Generator using Liquid Metal as Working Fluid Coupled with Steam Generator

As shown in the figure, liquid potassium is used as working fluid, which is heated in a breeder reactor and passed through a nozzle to increase its velocity. The vapour formed due to nozzle action is separated in the separator and condensed then the condensed working fluid is pumped back to the reactor. The liquid that comes out from the separator is passed through the MHD generator to produce D.C power. The liquid potassium coming out of the MHD generator is allowed to pass through the conventional steam plant. The heat of the liquid potassium is used in the heat exchanger to produce the steam, which is utilized to run steam turbine generator, thus producing electricity.

Q38. Write the advantages and disadvantages of MHD systems.

Answer :

Advantages

The advantages of MHD system are as follows.

1. The conversion efficiency can be around 50%, while the most efficient steam plants having 40% conversion efficiency.
2. Since it has no moving parts, it is more reliable.
3. It generates large amount of power.
4. The power produced by the closed cycle MHD system is free of pollution.
5. As soon as it is started, it can able to reach the full power level.
6. Compared to conventional fossil fuel plants, the size (m^3/kw) of the MHD plants is significantly less.
7. The overall operational costs are about 20% less than that of conventional steam plants.
8. The capital costs of MHD plants are comparable to that of conventional steam plants.
9. Due to direct conversion of heat into electricity, the use of the gas turbine or both gas turbine and boiler is eliminated. Thus, the energy losses are reduced.
10. The MHD system has the advantages of better fuel utilisation.
11. It is suitable for peck power generation.

Disadvantages

The MHD system have the following disadvantages.

1. The MHD system has high friction losses (About 12% of the input) and heat transfer losses.
2. In MHD systems,the reverse flow of electrons may occur through the conducting fluids around the ends of the magnetic field.
3. The MHD systems require very large magnets which are expensive.
4. Since the combustor, MHD duct, electrodes and air preheaters are exposed to corrosive combustion gases at very high temperatures the life of these equipment is reduced.
5. The separation of seed material from the conversion of potassium sulphate back to potassium carbonate is a difficult task.

Q39. Discuss about the economic aspects of MHD systems.

Answer :

Coal fired MHD steam power plants are commercially viable and are in practice. These plants setup against the conventional coal fired steam thermal power plants, these plants are better in terms of both environment and economics over conventional steam thermal plants.

The overall thermal efficiency of the MHD steam plants is about 50% to 60% while in case of most efficient conventional steam thermal plants, the efficiencies are in the range of 30% to 40%. Thus, the fuel consumption and emission would be reduced by 15% to 25%, this is the main advantages of the MHD plants. The comparative costs for coal fired steam thermal plant and MHD steam plants are shown in below table.

Particular	*MHD-Steam Plant*	*Conventional Steam plant*
Total cost of installation $/kW, (1900 Base)	1000	1000
Thermal Efficiency of Plant	48%	32%
Fuel Costs $/kWh	0.002	0.0026
Cost of Electricity $/kWh	0.009	0.002

Though the MHD power plants are preferable over conventional steam plants, they have some technological problems related with design, materials selection, high temperatures, reliability, service life, etc.

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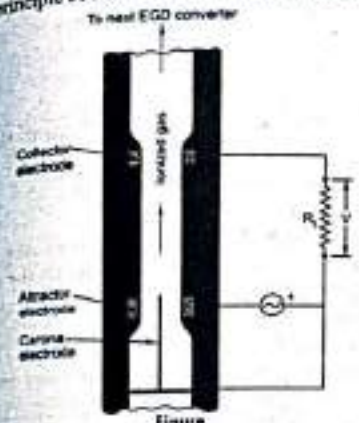
Q40. What is meant by Electron gas dynamic conversion and where do you use this principle?

May-17, (ME), (R13), Q11(b)

Answer :

The Electron Gas Dynamic generator (EGD), in which potential energy of a high pressure gas to carry the electrons from low potential electrode to a high potential electrode,thereby doing work against the electric filed. The constriction and working principle of EGD is shown in below figure.



Figure

As shown in the figure the EGD consists of a duct that is electrically insulated, corona electrode, attractor electrode, collector electrode, ionised gas and an external load.

The corona electrode placed at the entrance of the duct produces electrons. Then this ionised gas particles are carried down the duct with the neutral atoms. The collector electrode located at the end of the insulated duct neutralise the ionised particles. The most commonly used working fluids in EGD are, other combustion gases produced by burning of fuel at high pressures or pressurised reactor gas coolant. The maximum power output per the channel from EGD is about 10 to 10 W.

Thus, to obtain required amount of power output, several thousand channels are connected in series and parallel. The voltage produced is very high, in the order of 100000 to 200000 V. Thus, the EGD converter requires high voltage insulators like Beryllium oxide.

The efficiency of EGD is equal to MHD steam combination.

The EGD system has following advantages over MHD systems.

1. EGD systems can be operated at relatively low temperatures.
2. Injection and recovery of seed material is not required.
3. Large quantities of condenser cooling is not required.
4. Since EGD doe not need a steam generator, it is self contained.
5. Energy can be extracted till the gases reach almost the stack temperature.

5.3 Fuel Cells, Principle, Faraday's Laws, Thermodynamic Aspects, Selection of Fuels and Operating Conditions

Q41. With the help of a diagram, explain the operation of a fuel cell.

July-13, (ME), (R13), Q10(a)

OR

Explain the principle of operation of an alkaline fuel cell with the aid of a diagram.

April-18, (ME), (R13), Q11(b)

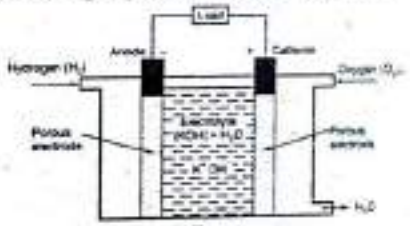
OR

Draw the line diagram and explain the working of hydrogen fuel cell.

Answer : [May-17, (ME), (R13), Q11(a) | Model Paper, Q11(b)]

Alkaline fuel cell was invented by a British scientist, Francis Thomas Bacon. Thus, this fuel cell is also known as Bacon's fuel cell or hydrogen -oxygen fuel cell.

In this cell, hydrogen is used as fuel and oxygen is used as oxidant, since these two elements are highly reactive with least complications. The potassium hydroxide (20% to 40% concentration) is used as the electrolyte, which has high electrical conductivity and is less corrosive than acids. The construction $H_2 - O_2$ fuel cell is shown as below figure.



Figure

Hydrogen-oxygen cell consists of three chamber, which are separated by two porous nickel electrodes (anode and cathode). The middle chamber (i.e., space between the two electrodes is filled with the aqueous solution of potassium hydroxide (KOH). The surfaces of the electrodes are treated with chemicals, so that the electrodes repel electrolytes. As a result, the leakage of potassium hydroxide into the outer chamber is minimised.

The fuel (i.e., hydrogen) is supplied to anode; it gets oxidized and releases H^+ ions. Free electrons flow through the external circuit form anode to cathode, which generates the electricity. Hydrogen ions (i.e.,H^+ ions) combine with the OH^- ions in the electrolyte solution to form four water molecules. Oxygen (O_2) is fed into the fuel cell at cathode, where it combines with the four electrons from the external circuit and react with water present in the electrolyte to form (OH^-) ions. These OH^- ions remain in the electrolyte to combine with incoming Hydrogen molecules. Thus, the electrolyte remains unchanged in terms of quantity and chemical composition.

The reaction are as follows,

$$4KOH \rightarrow 4K^+ + 4(OH)$$

At Anode

$$2H_2 \rightarrow 4H^+ + 4e^-$$
$$4H^+ + 4OH^- \rightarrow 4H_2$$
$$2H_2 + 4OH^- \rightarrow 4H_2 + 4e^-$$

At Cathode

$$O_2 \rightarrow 2O^-$$
$$2O^- + 2H_2O + 4e^- \rightarrow 4H_2O$$
$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

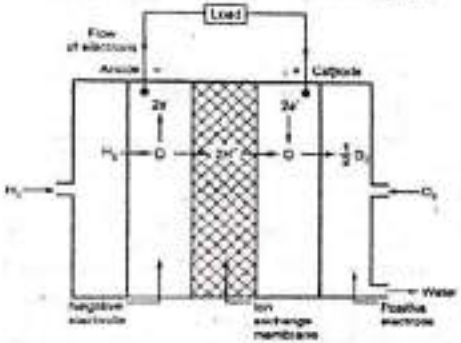
Cell Reaction

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Electrical Energy}$$

Q42. Explain the principle and working of ion exchange membranes fuel cell.

Answer :

The ion exchange membrane fuel cell is also called as polymer electrolyte membrane fuel cell (PEMFC). The schematic diagram of this cell is shown in below figure.



Figure

This cell consists of a solid electrolyte ion-exchange membrane, two electrodes and gas feed tubes (i.e., inlet and outlet sections).

The electrolyte is a solid polymer membrane of an organic material such as polystyrene sulphuric acid. This membrane allows the H^+ ions to pass through it, and is non permeable to the reactant gases, i.e., hydrogen and oxygen. In this cell, the hydrogen is used as fuel and the hydrogen ions are charge carriers. The hydrogen molecules is split into hydrogen ions and electrons at anode. These hydrogen ion pass through the electrolyte membrane and travel towards the cathode. The electrons flow through the external circuit and generates electric power. At cathode, the oxygen is supplied, and is combines with the electrons and hydrogen ions to produce water.

The cell reactions at anode and cathode are as follows,

At Anode

$$H_2 \rightarrow 2H^+ + 2e^-$$

At Cathode

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$

Overall Reaction

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Electrical energy}$$

The electrolyte membrane is coated with finely powdered platinum on both sides, which acts as catalyst for the cell reactions.

Q43. State the Faraday's laws of electrolysis.

Answer :

Faraday's Laws of Electrolysis

1. **First Law**

   The mass of the various products formed form the electrodes is proportional to the electric charge passed through the electrolyte.

2. **Second Law**

   For a specific charge passed through the electrolyte solution, the mass of the products formed are proportional to the electrochemical equivalent weight of the products.

Q44. What are the advantages and limitations of fuel cells over other direct energy conversion systems?

May-19, (R15), Q11(b)

OR

What are the advantages and disadvantages of fuel cells?

Answer :

The advantages and disadvantages of fuel cells are as follows,

Advantages

1. Conversion efficiencies i.e. are high (approximately 70%).
2. Transmission of power is not required because they can be installed near the use point.
3. No noise is produced, and it is odourless.
4. Space requirement is less compared to conventional power plants.
5. No cooling water is required.
6. The operation of fuel cell can be started in less time.
7. It requires less maintenance.
8. It is simple in construction and safe.
9. The operation of fuel cells is pollution free.
10. Capacity of the fuel cells can be increased as per the demand.

Disadvantages

1. Initial cost is high.
2. Service life is less.
3. Difficult to refill the fuel cells in vehicles.

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Q45. Explain about the thermodynamic aspects of fuel cells.

July-19, (R15), Q11(b)

Answer :

In fuel cell, the reactants are converted into products in a chemical reaction in a steady flow process. The work is determined by combining the first and second laws of thermodynamics for a steady flow process.

Consider a steady flow process.

According to the first law of thermodynamics,

$$\Delta Q - \Delta W = \Delta H + \Delta K.E. + \Delta P.E. \quad ...(1)$$

Where,

ΔQ – Heat transferred to the steady flow stream from the surrounding,

ΔW – Work done by the flow stream from entrance to exit

ΔH – Change in enthlpy of the flow stream from entrance to exit.

$\Delta K.E$ – Kinetic energy of the stream, and

$\Delta P.E.$ – Potential energy of the stream.

$K.E$ and $P.E.$ are usually negligible in fuel cells. Hence, the equation (1) can be written as,

$$\Delta W = \Delta Q - \Delta H \quad ...(2)$$

According to the second law of thermodynamics,

$$\Delta Q = T.\Delta S$$

From equation (1) and (2),

$$\Delta W_{max} = T.\Delta S - \Delta H \quad ...(3)$$

The gibbs free energy is given by,

$$\Delta G = \Delta H - \Delta T.\Delta S$$

Where, T is constant ...(4)

From equation (3) and (4),

$$\therefore \Delta W_{max} = -\Delta G$$

Efficiency of Fuel Cell (η_{rc})

The efficiency (η_{rc}) of energy conversion of a fuel cell is defined as "the ratio of the useful work to the heat of combustion of the fuel".

$$\text{i.e., } \eta_{rc} = \frac{\Delta W_{max}}{-(\Delta H)} = \frac{-(\Delta G)}{-(\Delta H)} \quad ...(5)$$

For hydrogen-oxygen fuel cell, at 25°C,

$$\Delta G = (-237191) \text{ kJ/kg more}$$

Heat of reaction $\Delta H = (-285838)$ kJ/kg more

Therefore,

$$(\eta_{rc})_{max} = \frac{237191}{285838} = 0.83 \text{ or } 83\%$$

E.M.F. of a Fuel Cell

The e.m.f. that will drive electrons through the external load is proportional to the change in Gibbs free energy.

$$\text{i.e., } E = \frac{-\Delta G}{nF} \quad ...(6)$$

Where,

E – Electromotive force

ΔG – Change in Gibbs free energy (J/mole)

n – Number of electrons per morel of fuel, and

F – Faraday's constant (= 96487 coulomb/mole)

From equation (5) and (6),

$$(\eta_{rc})_{max} = \frac{-nF.E}{\Delta H} \quad ...(7)$$

The overall efficiency of 'reversible fuel cell' is given by,

$$(\eta_{rc})_{max} = h_{rc} \times \text{loss factor} \quad ...(8)$$

The power output of a reversible fuel cell (P_{rev}) is given by

$$P_{rev} = \frac{\Delta G_{max}}{\text{Molar mass of hydrogen}} \quad ...(9)$$

The molar mass of hydrogen is equal to 2.016 kg/more.

Actual electrical power output is given by, ...(10)

$$Q = P_{rev} - P_{actual} \quad ...(11)$$

Voltage Efficiency (η_v)

All the losses in a fuel cell may be includedunder voltage efficiency.

It is given as,

$$\eta_v = \frac{\text{Operating voltage}}{\text{Theoretical voltage}} = \frac{V_c}{E} \quad ...(12)$$

Where, V_c – Operating voltage of the fuel cell at a given current density.

E – Theoretical open circuit voltage (e.m.f)

Q46. Explain about the operating characteristics of fuel cells.

Answer :

V.I and P.I characteristics of a fuel cell

The various operating characteristics of a fuel cell as follows,

1. Current-Voltage (V-I) characteristics.
2. Power-Current (P-I) characteristics

1. **Current-voltage (V-I) characteristics**

The cell voltage V_c versus electrode current density I_d curve is used to evaluate the performance of a fuel cell.

The cell voltage V_c drops with increase in I_d due to 'Polarization' within the cell. Hence, this curve is also known as the polarization curve of the fuel cell.

Polarization is main reason for internal energy loss, and is measured in terms of polarization voltage V_p.

$$\Delta V_c = E - V_c \quad ...(1)$$

i.e., E = E.m.f of the cell, and

V_c = On-load voltage of the cell.

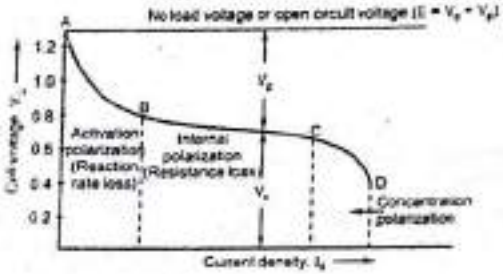

Figure (1): V-I (V_c vs I_d) Characteristics of fuel cell

With increase in load of the cell the internal losses increase. As a result, there is a drop in the cell terminal voltage(V_c).

2. **Power-Current (P-I) characteristics**

Power per cell, $P_c = V_c \times I_c$ ...(2)

With the increase in current density, the power of a cell increases till the saturation point is reached, then it decreases due to polarization effects.

Output power = Input power – Polarization losses

Efficiency of fuel cell is given by,

$$\eta_{fc} = \frac{\text{Output power}}{\text{Input power}} \quad ...(3)$$

The efficiency of the fuel cell can also be calculated as follows,

$$\eta_{fc} = \frac{\text{On-load cell voltage}}{\text{No-load cell voltage}} = \frac{V_c}{E} = \frac{E - V_p}{E}$$

The power and efficiency characteristics of a fuel cell is shown in below figure.

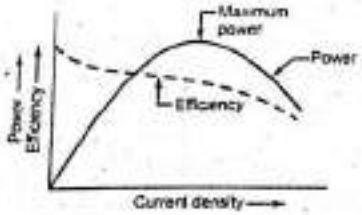

Figure (2): Power and efficiency characteristics of a fuel cell

From the above figure, it is observed, That,

1. The efficiency of a fuel cell varies with the current density at electrode surface due to the polarization effects.
2. The power losses is converted to waste heat and released into atmosphere.

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Q47. Comment on relative performance of fuel cells.

June-18, (R13), Q1(b)

Answer :

Relative performance various fuel cells are given in below table

Sl. No.	Type of Fuel cell	Fuel	Electrolyte	Capacity [kW_e]	Efficiency [%]	Working Temperature [°C]	Applications
1.	Proton Exchange Membrane (PEM) or solid polymer	H_2, CH_4, CH_3OH	Polymer Membrane	upto 250	60 (H_2) 40 (CH_4)	60 – 80°	Cars, buses, home, CHP plants
2.	Solid oxide (SOFC)	H_2, CH_4, coal gas	$Zr(y)O_2$	10 – 25	50 – 65	800 – 1000	Domestic, small plants, CHP plants
3.	Alkaline (AFC)	Pure H_2	KOH	20	60	60 – 90	space crafts, boats
4.	Molten carbonate (M C F C)	H_2, CH_4 coal gas	Molten carbonate of Li, Na and K	2200 (max)	48 – 60	650	Small plants, CHP plants.
5.	Direct methanol (D M F C)	CH_3OH	Polymer membrane	N.A.	40	60 – 130	Small domestic plant, CHP plants
6.	Phosphoric Acid (P A F C)	$H_2(CH_4)$	H_3PO_4	1100 (max)	40	130 – 220	Small power plants, CHP plants.
7.	Regenerative (R F C)	H_2	N. A.	N. A.	N. A.	upto 120	Domestic, CHP plants.

Q48. Explain about the various fuels used in fuel cells.

Answer :

The common fuels used in fuel cells are as follows.

1. **Hydrogen**

The pure hydrogen is consider as the premium fuel for all fuel cells. Pure hydrogen in combination with pure oxygen is used as the fuel in space and military applications. But, the production and storage of pure hydrogen involves high cost. As an alternative method, hydrogen rich gases can be obtained from reforming of other fuels, which is more economical.

2. **Hydrazine (N_2H_4)**

This is a liquid fuel which can be stored very easily, and it has high energy density. But, it is highly reactive, toxic and costly. This fuel can be used directly without any transformations.

3. **Ammonia (NH_3)**

It is a type of indirect fuel. Generally, it can be stored in liquid state, and it is possible to decompose catalytically at high temperature. The hydrogen produced during the decomposition process is burnt in air to provide the required heat for decomposition. If the mixture of H_2 and N_2 is used in the fuel cell, the nitrogen present in the mixture is sent out through the exhaust.

4. **Gaseous Hydrocarbons**

In case of gaseous hydrocarbons, first, the mixture of H_2 and CO is produced from hydrocarbons such as methane, propane, etc, by steam forming.

$$\text{Hydrocarbons}(CH_4, C_3H_8, \text{etc.}) \xrightarrow{\text{steam forming at}} H_2 + CO$$

Then this mixture is used as fuel without any alterations or it is used after the removal of CO by water gas shift reaction.

Examples : Natural gas, LPG, biogas, coal gas, land fill gas and gasified coal.

5. **Liquid Hydrocarbons**

Similar to gaseous hydrocarbons, these also first transformed to H_2 and CO by steam reforming process.

Then this mixture is used as fuel.

6. **Synthesis Gas**

Synthesis gas is a mixture of H_2 and CO in various proportions along with other impurities. These mixtures can be produced economically from both conventional and non conventional source.

(i) In MCFC and SOFC (H_2 + CO) mixture is used as fuel.

(ii) In hydrogen fuel cells, CO is removed and H_2 content is increased by water gas shift reaction.

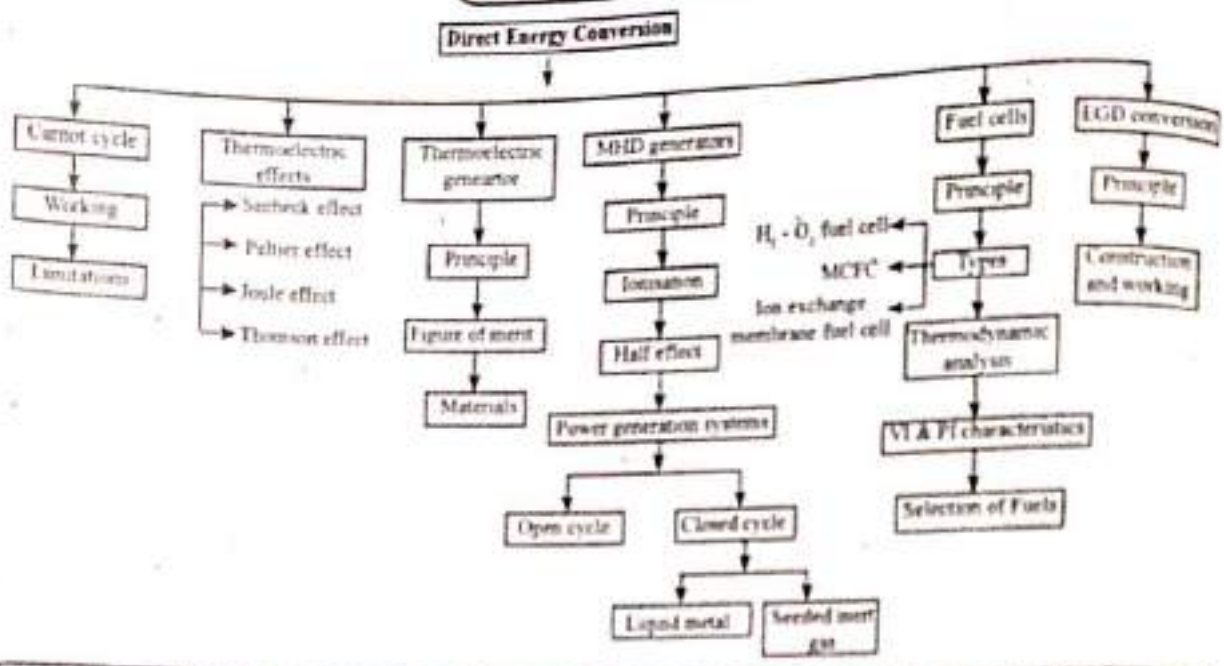
$$\underset{\text{(Steam)}}{CO + H_2O} \xrightarrow[\text{Catalyst and Chromium oxide fuel}]{\text{at 400°C and 27 atm}} CO_2 + H_2 + 1440\ \text{kJ/kg} \text{ (Energy)}$$

(iii) In case of AFC, CO_2 present in the products is removed.

7. **Methanol**

Methanol can be used as both direct and indirect type fuel. It is transformed to a mixture of H_2 and CO with the help of steam at about 200°C in presence of catalyst.

MEMORY MAP



FREQUENTLY ASKED QUESTIONS AND IMPORTANT QUESTIONS

Q1. With the help of a diagram, explain the operation of a fuel cell. 3 TIMES

Ans: Refer Q41.

[July-19, (R15), Q10(a) | April-18, (R13), Q11(b) | May-17, (R13), Q11(a)]

Q2. List out the limitations of Carnot cycle. 2 TIMES

Ans: Refer Q3.

[April-18, (R13), Q1(i) | May-17, (R13), Q1(i)]

Q3. Explain the working details of MHD accelerator 2 TIMES

Ans: Refer Q29.

[May-17, (R13), Q10(b) | May-13, (R09), Q8(b)]

Q4. Describe MHD closed cycle system, with its advantages and disadvantages. 2 TIMES

Ans: Refer Q36.

[May-19, (R15), Q10(a) | June-18, (R13), Q10(b)]

Q5. Explain the principle of Thermionic generator. Important Question

Ans: Refer Q6.

Q6. Differentiate Seebeck and Peltier effect. Important Question

Ans: Refer Q11.

Q7. Describe briefly the working of a thermoelectric generator. Important Question

Ans: Refer Q21.

Q8. What is meant by Electron gas dynamic conversion and where do you use this principle? Important Question

Ans: Refer Q40.

Q9. Explain about the thermodynamic aspects of fuel cells. Important Question

Ans: Refer Q45.

Q10. Comment on relative performance of fuel cells. Important Question

Ans: Refer Q47.

Q11. Explain the principle of dissociation and ionization with respect to MHD. Important Question

Ans: Refer Q33.

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