Module – 1

1.1 Introduction:

Energy can neither be created nor be destroyed, but it can transfer from one form to another form.

Energy is an important input for all sectors of any nation and its economy is dependent on energy. The standard of living of any nation can be directly related to its per capita energy consumption.

Energy crisis is due to two reasons.

- World's population is keeps on increasing.
- Standards of living of human beings are kept on changing.

If we take annual per capita income of various nations and plot them against per head energy consumption, it will appear that per capita energy consumption is a measure of per capita income or the per capita energy consumption is a measure of prosperity of the nation. [1]

For easy understanding the per capita energy consumption of the selected nations is tabulated in table 1.1

Table 1.1 per capita energy consumption for selected nations

Sl No	Country	Per capita energy consumption
1	United States	317 million Btu
2	Russia	206 million Btu
3	Japan	171 million Btu
4	China	076 million Btu
5	India	019 million Btu

BTU-British thermal units, A "British thermal unit" (Btu) is a measure of the heat content of fuels. It is the quantity of heat required to raise the temperature of 1 pound of liquid water by 1°F at the temperature that water has its greatest density (approximately 39°F).

By observing the table 1.1 one can easily conclude that United States per capita energy consumption is 16.68 times greater than our nation. Our neighbor china is also 4 times greater. [2]

Btu Conversion Factors [3]

Table 1.2 BTU conversion factos

Energy Source	Physical Units and Btu (Weighted Averages, 2011)
Electricity	1 kilowatthour = 3,412 Btu *(but 7,000 to 11,500 Btu of primary to generate the electricity in fossil fuel fired power plants)*
Natural Gas	1 cubic foot = 1,023 Btu 1 cubic foot = 0.01 therms
Motor Gasoline	1 gallon = 124,238 Btu
Diesel Fuel	1 gallon = 138,690 Btu
Heating Oil	1 gallon = 138,690 Btu
Propane	1 gallon = 91,333 Btu
Wood	1 cord = 20,000,000 Btu

1.2 Energy Source:

Difference between source and resource

Table 1.3 Difference between source and resource

Source	Resource
Source is a place or thing that provides us what we are looking for. Example: A teacher is a source of knowledge, while sun is a source of energy, A well is source of underground water	Something is valuable for us and something that we consume to serve a function. Example: resources are things that are valuable to people or a nation for its development, and that is why government all over the world are looking for resources of energy that are renewable or reusable

Energy resources: energy resources are the main sources of energy from which the energy can be extracted and utilized for mankind. Energy is a key input for economic growth. The growth of a nation is largely depends upon availability of energy resources.

1.3 *India's production and reserves of commercial energy sources*[4]

In GWS

Table 1.4 ***India's production and reserves of commercial energy sources***

States/UT	Hydro		Thermal		Nuclear		New & renewable **		Total		Growth rate *
	31-03-2011	31-03-2012	31-03-2011	31-03-2012	31-03-2011	31-03-2012	31-03-2011	31-03-2012	31-03-2011	31-03-2012	
NORTHERN REGION											
Delhi	00.00	00.00	01.51	01.54	00.00	00.00	00.00	00.02	01.51	01.56	03.48
Haryana	00.88	00.88	03.44	03.85	00.00	00.00	00.11	00.12	04.43	04.86	09.64
Himachal Pradesh	00.97	02.07	00.00	00.00	00.00	00.00	00.38	00.53	01.35	02.60	92.95
Jammu & Kashmir	00.78	00.78	00.18	00.18	00.00	00.00	00.13	00.13	01.09	01.09	00.11
Punjab	02.23	02.23	02.66	02.66	00.00	00.00	00.33	00.35	05.21	05.24	00.47
Rajasthan	00.99	00.99	04.33	04.60	00.00	00.00	01.47	02.37	06.78	07.95	17.21
Uttar Pradesh	00.52	00.52	04.67	07.12	00.00	00.00	00.61	00.69	05.81	08.33	43.44
Uttrakhand	01.65	01.65	00.00	00.00	00.00	00.00	00.15	00.19	01.80	01.84	02.21
Central Sector	05.79	05.99	11.59	12.84	01.62	01.62	00.00	00.00	19.01	20.46	07.63
Sub total	**13.82**	**15.12**	**28.38**	**32.79**	**01.62**	**01.62**	**03.17**	**04.39**	**46.99**	**53.93**	**14.76**
WESTERN REGION											
Chhatisgarh	00.12	00.12	03.66	03.89	00.00	00.00	00.25	00.27	04.03	04.29	06.36
D & N Haveli	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
Daman & Diu	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00
Goa	00.00	00.00	00.05	00.05	00.00	00.00	00.03	00.03	00.08	00.08	00.00
Gujarat	00.77	00.77	10.34	14.73	00.00	00.00	02.00	03.50	13.11	19.00	44.92
Madhya Pradesh	01.70	01.70	02.81	02.81	00.00	00.00	00.27	00.48	04.78	04.99	04.39
Maharashtra	03.33	03.33	11.05	13.39	00.00	00.00	02.81	03.63	17.19	20.35	18.36
Central Sector	01.52	01.52	11.01	12.33	01.84	01.84	00.00	00.00	14.37	15.69	09.18
Sub total	**07.45**	**07.45**	**38.92**	**47.20**	**01.84**	**01.84**	**05.36**	**07.91**	**53.56**	**64.39**	**20.22**
SOUTHERN REGION											
Andra Pradesh	03.70	03.73	07.73	08.38	00.00	00.00	00.77	00.89	12.19	13.00	06.62
Karnataka	03.60	03.60	03.91	05.01	00.00	00.00	02.62	03.18	10.13	11.80	16.44
Kerala	01.88	01.88	00.43	00.43	00.00	00.00	00.15	00.16	02.46	02.47	00.68
Lakshadweep	00.00	00.00	00.03	00.03	00.00	00.00	00.00	00.00	00.01	00.01	-07.00
Puducherry	00.00	00.00	00.03	00.03	00.00	00.00	00.00	00.00	00.03	00.03	-00.08
Central Sector	00.00	00.00	08.75	10.00	01.32	01.32	00.00	00.00	10.07	11.32	12.41
Sub total	**11.30**	**11.34**	**25.52**	**28.52**	**01.32**	**01.32**	**09.34**	**11.57**	**47.48**	**52.75**	**11.09**
EASTERN REGION											
A & N Island	00.00	00.00	00.06	00.06	00.00	00.00	00.01	00.01	00.07	00.07	00.00
Bihar	00.00	00.00	00.53	00.53	00.00	00.00	00.07	00.08	00.60	00.61	02.01
Jharkhand	00.13	00.13	01.55	02.60	00.00	00.00	00.00	00.00	01.68	02.73	62.11
Odisha	02.06	02.06	01.62	02.22	00.00	00.00	00.08	00.10	03.76	04.38	16.42
Sikkim	00.00	00.00	00.01	00.01	00.00	00.00	00.05	00.05	00.05	00.06	09.60
West Bengal	00.98	00.98	06.25	06.48	00.00	00.00	00.16	00.16	07.37	07.62	03.40
Central Sector	00.71	00.71	09.02	10.27	00.00	00.00	00.00	00.00	09.73	10.98	12.85
Sub total	**03.88**	**03.88**	**19.02**	**22.17**	**00.00**	**00.00**	**00.36**	**00.40**	**23.26**	**26.44**	**13.67**
NORTH EAST REGION											
Arunachal Pradesh	00.00	00.00	00.02	00.02	00.00	00.00	00.08	00.08	00.09	00.09	00.00
Assam	00.10	00.10	00.34	00.38	00.00	00.00	00.03	00.03	00.47	00.51	07.89
Manipur	00.00	00.00	00.05	00.05	00.00	00.00	00.01	00.01	00.05	00.05	00.00
Meghalaya	00.16	00.24	00.00	00.00	00.00	00.00	00.03	00.03	00.19	00.27	43.34
Mizoram	00.00	00.00	00.05	00.05	00.00	00.00	00.04	00.04	00.09	00.09	00.00
Nagaland	00.00	00.00	00.00	00.00	00.00	00.00	00.03	00.03	00.03	00.03	-06.52
Tripura	00.00	00.00	00.15	00.15	00.00	00.00	00.02	00.02	00.17	00.17	00.00
Central Sector	00.86	00.86	00.38	00.38	00.00	00.00	00.00	00.00	01.24	01.24	00.00
Sub total	**01.12**	**01.20**	**00.99**	**01.02**	**00.00**	**00.00**	**00.22**	**00.22**	**02.33**	**02.45**	**05.03**
Total states	**28.68**	**29.90**	**72.08**	**85.88**	**00.00**	**00.00**	**18.42**	**24.49**	**119.21**	**140.24**	**17.67**
Total central	**08.89**	**09.09**	**40.75**	**45.82**	**04.78**	**04.47**	**00.00**	**00.00**	**54.41**	**59.68**	**09.69**
Total all India	**37.57**	**38.99**	**112.82**	**131.70**	**04.78**	**04.78**	**18.45**	**24.49**	**173.63**	**199.96**	**15.17**

**:- Renewable Energy Sources includes Small Hydro Projects, Wind Power, Biomass Power, Biomass Gasified, Urban & Indus trial Waste and Solar Power.

* Growth rate of total installed electricity generating capacity of India

Sub-totals /Totals may not tally due to conversion to GW and rounding off.

Source: Central Electricity Authority.

1.3.1 Indian Energy Scenario

- Describe the future of non-conventional energy sources in India.
- What is meant be renewable energy sources? Explain in brief these energy sources with special reference to India.
- Discuss the possibility of exploiting the non-conventional energy in India.
- Discuss in details about reserves and production of petroleum and natural gas in India with problem area.
- Describe the various non-conventional energy resources relevant to India.
- Write your views on energy planning issues aiming to bridge the gap between the energy demand and supply situation in India.
- Describe the energy position in India.
- Give brief review of various sources of renewable energy.

In India, enormous demand for electricity has arisen due to the economic growth during the past two decades. In India, the total power generation capacity in 1947 was only 1360 MW. According to the five-year plans, the total power generation capacity should be 425,000 MW by 2007 but actual installed capacity is much lower. However with the liberalization of Indian economy, the power sector has been made open to the private sector, and it is now expected that the growth rate of power generation capacity will be faster than what is estimated in the five-year plan. Generation capacity by different types of power plants in India as planned is shown in Table 1.5. However, at present the total installed generation capacity is about 182,689 MW. The breakdown of the same as per sector and type of fuels is shown in Tables 1.6 and 1.7.

Table 1.5 Indian generation capacity (in MW) as planned

Power plant	Year (1991)	8th Plan (1997)	9th Plan (2001)	10th Plan (2007)	Total
Thermal	45,000	28,000	32,000	58,000	16,3000
Hydro	18,443	8,680	26,000	23,000	76,123
Nuclear	1,500	1,320	2,880		5,700
Others		38,000	61,000	81,000	180,000
Total	64,943	76,000	121,880	162,000	424,823

Table 1.6 Total installed capacity as per sector in India

Sector	MW	%
State sector	83,563.65	47.74
Central sector	56,572.63	30.96
Private sector	42,553.34	23.29
Total	182,689.62	

Table 1.7 Total installed capacity as per the fuel type in India

Fuel	MW	%
Total thermal	119,040.90	65.16
Coal	100,098.38	54.29
Gas	17,742.85	09.71
Oil	1,199.75	00.65
Hydro	38,706.40	21.18
Nuclear	4780.00	02.16
RES (Renewable Energy Sources)	20,162.24	11.03
Total	**1,82,689.62**	**100.00**

Nuclear energy: About 2.39% of power generating capacity is nuclear based in India. It corresponds to about 4780 MW of the installed capacity. Tarapore was the first atomic power station with foreign technology and Kalpakkam atomic power plant in Madras in 1983 was first indigenously commissioned plant. The nuclear fuel such as uranium is found in Bihar, Rajasthan and Chennai. Uranium reserve in India is estimated to be about 33,000 tons. Thorium is another nuclear fuel and it is present in the monazite beach sand in Kerala Bhabha Atomic Research Centre (BARC) at Trombay is the major centre for research in atomic energy in India. The nuclear power plants are as follows:

Sl No	Plant Location	Installed capacity	Under construction
01	Rawatbhata, Rajasthan	100+200+4*220=1800MW	2*700=1400MW
02	Narora, Uttar Pradesh	2*220=440MW	
03	Kakrapur, Gujarat	2*220=440MW	2*700=1400MW
04	Tarapur, Maharashtra	2*160+2*540=1400MW	
05	Kaiga, Karnataka	4*220=880MW	
06	Kalpakkam, Tamil Nadu	2*220=440MW	1*500=500MW
07	Kudankulam, Tamil Nadu		2*1000=2000MW

Table 1.8 Nuclear Power Plants in India

Solar energy: Solar electrification in remote villages has begun. Salijipally in Andhra Pradesh became the country's first village to be electrified using SPY (Solar photovoltaic) system. The first two 100 KW partial grid interactive SPY power projects at Kalyanpur in Aligarh district and Saraisadi in More district have been commissioned. Work on solar power is being carried out by

a. IIT, Mumbai,
b. BHEL, Hyderabad,
c. NPL, New Delhi, and
d. NAL, Bangalore.

Fossil fuels: The amount of coal deposition in India is estimated to be about 85,000 million tons. The major portion, that is 60% of the coal, exists in the eastern part of the country, which includes Jharkhand and West Bengal. The low-grade coal called lignite is found in Tamil Nadu and Rajasthan.

Some of the thermal power plants in India are shown in Table 1.9.[5]

Sl No	Power Plant Name	Operator	Location & District	State	Capacity (MW)
01	Mundra Thermal Power Station	Adani Power	Mundra, Kutch (dist)	Gujarat	4,620
02	Vindhyachal Super Thermal Power Station	National Thermal Power Corporation (NTPC)	Vindhya Nagar, Singrauli (dist)	Madhya Pradesh	3,760
03	Barh Super Thermal Power Station	National Thermal Power Corporation (NTPC)	Barh, Patna (dist)	Bihar	3,330
04	NTPC Ramagundam	National Thermal Power Corporation (NTPC)	Jyothi Nagar, Karimnagar (dist)	Andra Pradesh	2,600
05	Farakka Super Thermal Power Station	National Thermal Power Corporation (NTPC)	Farakka, Murshidabad (dist)	West Bengal	2,100
06	NTPC Dadri	National Thermal Power Corporation (NTPC)	Vidyutnagar, Gautam Budh Nagar (dist)	Utter Pradesh	1,820
07	Raichur Thermal Power Station	Karnataka Power Corporation Limited (KPCL)	Raichur (dist)	Karnataka	1,720
08	Kothagudem Thermal Power Station	Andhra Pradesh Power Generation Corporation (APGENCO)	Paloncha, Khammam (dist)	Andra Pradesh	1,720
09	Tuticorin Thermal Power Station	Tamil Nadu Electricity Board (TNEB)	Tuticorin (dist)	Tamil Nadu	1,050
10	Neyveli Thermal Power Station I	Neyveli Lignite Corporation (NLC)	Neyveli, Cuddalore (dist)	Tamil Nadu	1,020
11	JSW Power Plant	Jindal South West	VijayNagar, Bellary (dist)	Karnataka	860
12	Badarpur Thermal Power Station	National Thermal Power Corporation (NTPC)	Badarpur, New Delhi	Delhi	705
13	Bellary Thermal Power station	Karnataka Power Corporation Limited (KPCL)	Kudatini, Bellary (dist)	Karnataka	500
14	Udupi Thermal Power Plant	Lanco	Nandikoor, Udupi (dist)	Karnataka	600

Table 1.9 Few Thermal Power Stations installed in India

Wind energy: The total wind energy potential is estimated in India as 1,51,918 MW[7] also India is the 5th Largest wind power generating nation among the globe. Currently, total capacity of 20,149 MW has been installed and 6.3% of total world share[6]. Table 1.10 shows few installed wind mills in India. Also table 1.11 shows the state wise distribution

Power Plant	Producer	Location	State	Total Capacity in (MW)
Muppandal windfarm	Muppandal Wind	Kanyakumari	Tamil Nadu	1500.0
Jaisalmer Wind Park	Suzlon Energy	Jaisalmer	Rajasthan	1064.0
Brahmanvel windfarm	Parakh Agro Insdusries	Dhule	Maharashtra	528.0
Dhalgaon Windfarm	Grade Marine Exports	Sangli	Maharashtra	278.0
Vankusawade Windpark	Suzlon Energy	Satara	Maharashtra	259.0
Acciona Tuppadahalli	Tuppadahalli Energy India Private Limited	Chitradurga	Karnataka	56.1
Dangiri Wind Farm	Oil India limited	Jaiselmer	Rajasthan	54.0
Cape Comorin	Aban Loyd Chiles Offshore Ltd.	Kanyakumari	Tamil Nadu	33.0
Kayathar Subhash	Subhash Ltd.	Kayathar	Tamil Nadu	30.0

Table 1.10 Wind mills installed in India (more than 30MW plants)

Sl No	State	Wind power Installed capacity as on 31-03-2014
01	Tamil Nadu	7162.18
02	Gujarat	3174.58
03	Maharashtra	3021.85
04	Rajasthan	2684.65
05	Karnataka	2135.50
06	Andra Pradesh	447.65
07	Madhya Pradesh	386.00
08	Kerala	35.10
09	Others	1101.49
	Total	20149.00

Table 1.11 State wise wind mill distribution in India

Hydel Energy: The total hydel energy potential is estimated in India as 1,48,701 MW[8], out of which 35,944.5 MW is under operation, 13,131.3 MW is under construction, 49,075.8 MW is the capacity under construction and operation. But still 96,244.2 MW is yet to be taken for construction. Table 1.12 shows few installed hydel power stations in India.

Sl No	Power Plant Name (Dam)	Operator	State	Capacity (MW)
01	Tehri Dam	Tehri Hydro Development Corporation Limited (THDC)	Uttarakand	2,400
02	Koyna	MahaGenco (Maharashtra State Power Generation Company Limited - MSPGCL)	Maharashtra	1,960
03	Srisailam Dam	Andhra Pradesh Power Generation Corporation (APPGC)	Andra Pradesh	1,670
04	Sharavathi	Karnataka Power Corporation Limited (KPCL)	Karnataka	1,469
05	Bhakra Dam	Bhakra Management Board Karamchari Sangh (BMBKS)	Punjab	1,325
06	Kalinadi	Karnataka Power Corporation Limited (KPCL)	Karnataka	1,240
07	Chamera Dam	National Hydroelectric Power Corporation (NHPC)	Hichamal Pradesh	1,071

Table 1.12 Few Hydel Power Stations installed in India

1.3.2 Energy Resources

- What do you understand by energy resources?

Energy resources are the main sources of energy from which the energy can be extracted and utilized for mankind. Energy is a key input in economic growth. The growth of a nation is largely depends upon the energy resources.

1.3.3 Classification of Energy Resources

- How can energy resources can be classified?
- Discuss the primary and secondary energy resources. Also, describe the future of non-conventional energy resources in India?
- What are the conventional and non-conventional energy sources? Describe the fossils fuels as the conventional energy resources.

The energy resources can be classified on the basis of usability of energy resources, traditional usage of energy resources, long-term availability of energy resources, commercial application of resources and origin of resources.

- **Primary and secondary energy resources**
    i. Primary resources: Resources available in the nature in the raw form are called primary resources. Fossil fuels (coal, oil and gas), uranium and hydro power are primary energy resources. These energy resources cannot be used in raw form. Primary energy resources have to be located, extracted, processed and converted into a suitable form before use.
    ii. Secondary resources: Secondary energy resources are obtained from primary energy resources by processing. Processing helps in transformation of primary resources into the secondary or usable energy form so that it can be utilized by consumers. Electricity, steam, hot water, petrol, diesel, LNG and CNG are secondary energy resources.

- **Conventional and non-conventional energy resources**
    i. Conventional: Conventional energy resources are energy resources which have been traditionally used from many years. These resources are also widely used at present and likely to be depleted.
    ii. Non-conventional: These are alternate energy resources to the conventional energy resources which are being considered to be used on large scale. The conventional energy resource are likely to be depleted in about 50-60 years and non-conventional energy resources should be fully developed by then to meet the energy requirement.

The comparison of conventional and non-conventional energy resources is given in Table 1.13

Table 1.13 Comparison between conventional and non-conventional resources

Conventional resources	Non-Conventional resources
• Traditional	• Non Traditional
• These have been in use for many years	• These are not in routine use at present
• These resources can be easily converted into mechanical energy	• These resources require some costly method to be converted into mechanical energy
• These are likely to be depleted, that is, these have limited availability	• These are no depletable or may be available in vast quantities
• Coal, petrol, diesel, nuclear fuels, CNG and LPG are conventional energy resources	• Solar, wind, tidal, geothermal and biogas are non-conventional energy resources.

- **Renewable and non-renewable energy resources**
  i. Renewable: Resources which can be renewed by nature again and again so that their supply is not adversely affected by the rate of their consumption are called renewable resources.
  ii. Non-renewable: Resources which are available in certain finite quantity and cannot be replenished are called non-renewable.

The comparison of renewable and non-renewable energy resources is given in Table 1.14

Renewable resources	Non-renewable resources
• These are inexhaustible resources • These are non-traditional in use • New methods are being developed to use these resources • Efforts are taken to make vast use of these resources • Hydel, solar, wind, tidal and geothermal resources are renewable energy resources	• These are exhaustible resources • These are traditional in use • Widely used as energy resources • Efforts are taken to conserve these resources • Fossil fuels, nuclear fuels and natural gases are non-renewable energy resources

Table 1.14 Comparison between renewable and non-renewable resources

- **Commercial and non-commercial energy resources**
  i. Commercial energy resources: The secondary usable energy resources such as electricity, CNG, LPG, petrol and diesel are essential for commercial activities. The economy of a nation highly depends on its ability to process and transform the natural raw energy sources into usable commercial energy sources.
  ii. Non-commercial energy: The energy which can be derived directly from nature so as to be used without passing through any commercial outlet is known as the non- commercial energy. Wood, animal dung cake and crop residues are non-commercial energy sources.

1.4 Need for non-conventional energy sources

- Why importance is being given to non-conventional energy resources?

There is a growing concern worldwide on the use of fossil fuels for the following reasons:

1. There is ever-increasing use of fossil fuels
2. Depletion of fossil fuels is taking place at a rapid pace.
3. There may be oil crisis as happened in 1973. Organization of Petrol Exporting Countries (OPEC) put an embargo on oil production in 1973

and these countries started oil pricing control strategy, resulting in severe energy crisis and steep rise in oil prices worldwide.

Owing to above reasons, more importance is being given to the development of alternative sources of energy such as non-conventional, renewable and environmental-friendly. The importance of non-conventional energy resources is also increasingly felt due to the following reasons:

1. The demand of energy is rapidly increasing due to fast industrialization and population growth. The conventional energy resources are insufficient to meet such growing demand.
2. The conventional energy resources are non-renewable and these are depleting fast.
3. The conventional energy resources (fossil fuels) on usage cause pollution, thereby degrading the environment.
4. The projects to harness large hydro resources affect wildlife, cause deforestation and affect nearby villagers due to submerging of a vast area.
5. Fossil fuels are also used as raw materials in the chemical industry. There is need to conserve fossil fuels for future generation.

It is important to explore and develop non-conventional energy resources to reduce excessive dependence on conventional resources. The present trend is to develop non-conventional resources to serve as supplement rather than alternative for conventional sources for some more time to come.

1.4 **Energy alternatives/types of energy resource**

1.4.1. Solar Energy:

- What is solar energy? Describe with the help of neat sketch the working of a solar plant.
- What do you understand by photovoltaic conversion? What are the advantages and disadvantages of solar energy?

The sun is a continuous fusion reactor in which hydrogen combines, to form helium and liberates large amounts of heat in the process. The sun rays contain a large amount of energy in the form of electromagnetic radiation due to the continuous nuclear fusion reaction taking place in the sun. The energy is released at the rate of 3.7×10^{20} MW. This heat energy contained in the sun rays can be utilized to generate electrical power. Out of which only 10^{17} Watts hits the atmosphere, and where as solar power available at the earth surface is 10^{16} watts, but for civilization the total power required is 10^{13} Watts.

The amount of solar energy is expressed in 'solar constant'. The solar constant the total energy that falls on a unit area exposed normally to the rays of the sun, at the average sun-earth distance. The most accepted value of solar constant is 1.353 kW/m^2. A number of scattering and absorption processes in the atmosphere reduce the maximum heat flux reaching the earth's surface is around 1 kW/m^2.

The sun rays are focused on solar collector to heat butane water to generate butane gas in the butane boiler. The butane gas under high pressure from the boiler is taken to butane turbine to perform mechanical work. A generator is coupled to the turbine to generate electrical power as shown in Figure 1.1. The potential of the power generation by solar energy can be in the order if 1.75 x 10^{11} MW. The mechanical devices which help to collect the solar radiations so as to convert them into heat energy are called solar collectors.

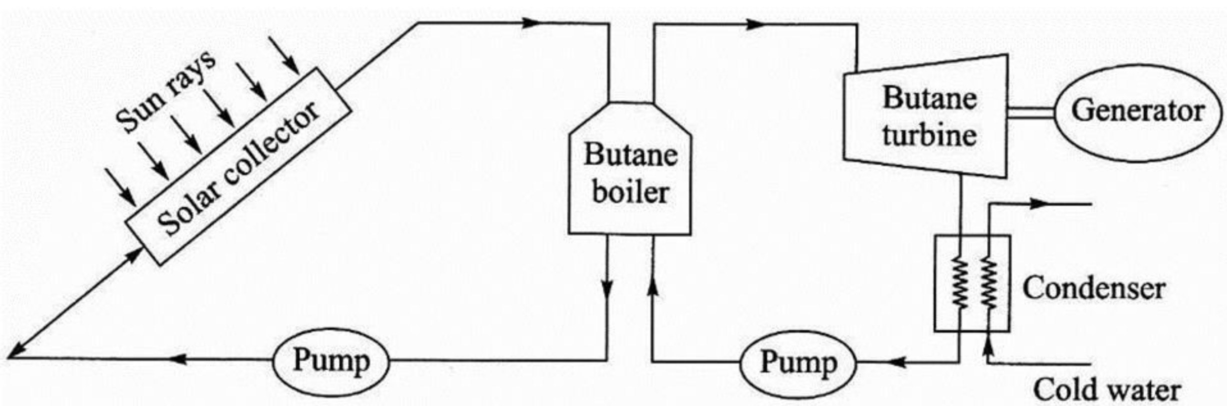


Figure 1.1 Working of a solar power plant

Photovoltaic conversion is a direct electricity generation method in which sunlight is converted into electricity using solar cells. The most common solar cells are manufactured from a highly refined silicon material. A single solar cell can produce electric power of 1 W at voltage of 0.5 V. Several solar cells can be connected in series or parallel to produce power of required voltage and current. Solar cells are an intermittent energy source and generally used with batteries to store generated electricity, thereby providing a more economical power generation system.

Advantages:

- It is renewable source of energy.
- Solar energy is available freely in nature.
- It does not pollute the environment.

- It can be directly converted into electrical energy by using photovoltaic cells.

Disadvantages:

- It is available only during daytimes and clear days.
- Low efficiency.
- It requires very large area to entrap appreciable solar energy for the generation of an economical amount of electricity.

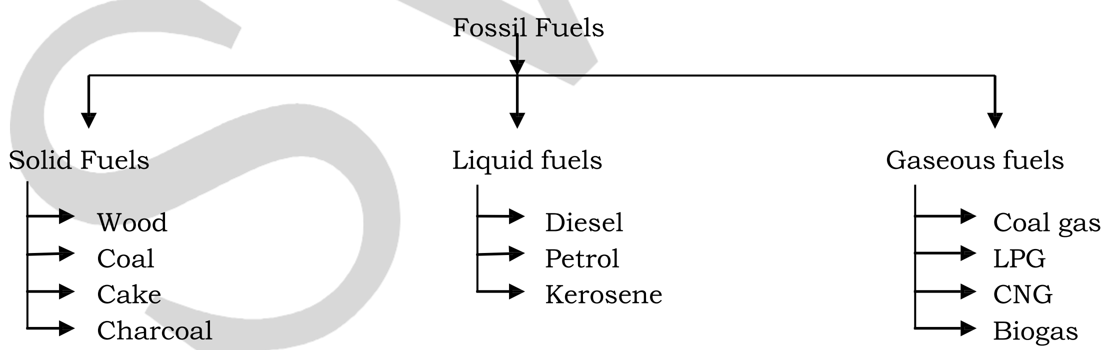
⇒ ***Impact on environment***

- Solar thermal system may pose a health hazard because of careless disposal of the heat transfer fluids used.
- Solar photovoltaic modules pose disposal problems owing to the presence of arsenic and cadmium.
- The total system comprising solar power generator with accessories contains several pollutants.
- Solar reflectors cause hazard to eyesight.

1.4.2. Thermal Energy:

- What is thermal energy? How fossil fuels are classified?

Classification of fossil fuels



Thermal energy is the energy which is stored as the heat energy in the fossil fuels. Fossil fuels are the fuels obtainable from the earth that have been accumulated over thousands and thousands of years by the decaying of plants, These fuels produce heat energy when they are burnt. Heat energy is mainly used for transportation and electric power generation in thermal power plants. The fossil fuels can be classified as shown.

Advantages[9]

- Fuel cost is comparatively less.
- Initial cost is less compared to other types of power generating systems for same power output.
- Space required is less compared to hydel plants.

Disadvantages

- It pollutes the atmosphere.
- Operating cost is high compared to hydel power plants

1.4.3. Water (hydro/hydel) Energy:

- What is hydel energy? Describe briefly a hydro electrical power plant.

Hydel energy is the potential energy of water created due to the storage of water at a higher level. A dam is built across the river to store water at a higher level. When this stored water in dam at the higher level flows under pressure to the lower level, it can run the turbine to generate electrical power. A hydroelectric power plant is shown in Figure 1.2. It consists of

(i) Reservoir,
(ii) Penstock to carry water from reservoir to turbine,
(iii) Turbine to convert water energy into mechanical work,
(iv) Generator to convert mechanical work into electrical energy and
(v) Power transmission system.

Advantages[10]

- Once a dam is constructed, electricity can be produced at a constant rate.
- If electricity is not needed, the sluice gates can be shut, stopping electricity generation. The water can be saved for use another time when electricity demand is high.
- Dams are designed to last many decades and so can contribute to the generation of electricity for many years / decades.
- The lake that forms behind the dam can be used for water sports and leisure / pleasure activities. Often large dams become tourist attractions in their own right.
- The lake's water can be used for irrigation purposes.
- The buildup of water in the lake means that energy can be stored until needed, when the water is released to produce electricity.

- When in use, electricity produced by dam systems does not produce green house gases. They do not pollute the atmosphere.

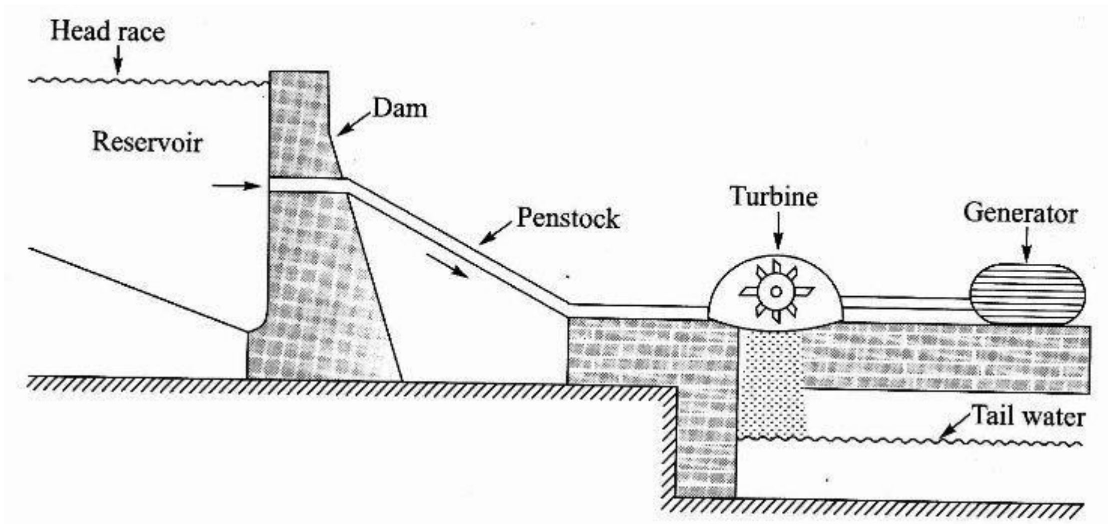


Figure 1.2 Hydel power plant

Disadvantages

- Dams are extremely expensive to build and must be built to a very high standard.
- The high cost of dam construction means that they must operate for many decades to become profitable.
- The flooding of large areas of land means that the natural environment is destroyed.
- People living in villages and towns that are in the valley to be flooded, must move out. This means that they lose their farms and businesses. In some countries, people are forcibly removed so that hydro-power schemes can go ahead.
- The building of large dams can cause serious geological damage. For example, the building of the Hoover Dam in the USA triggered a number of earth quakes and has depressed the earth's surface at its location.
- Although modern planning and design of dams is good, in the past old dams have been known to be breached (the dam gives under the weight of water in the lake). This has led to deaths and flooding.
- Dams built blocking the progress of a river in one country usually means that the water supply from the same river in the following country is out of their control. This can lead to serious problems between neighboring countries.

- Building a large dam alters the natural water table level. For example, the building of the Aswan Dam in Egypt has altered the level of the water table. This is slowly leading to damage of many of its ancient monuments as salts and destructive minerals are deposited in the stone work from 'rising damp' caused by the changing water table level.

1.4.4. Wind Energy:

- What is wind energy? How is wind mills classified? What are the advantages and disadvantages of wind energy? Why are blades made of fiber-reinforced plastic (FRP)?

Wind is induced in atmosphere by uneven heating of earth's surface by the sun. The wind energy is associated with the movement of large masses of air from cold to hot regions. The motion results from uneven heating of atmosphere by sun, thereby creating, temperature, density and pressure differences. The wind energy can be used to run windmill, which in turn will drive a generator to produce electric power or run water pumps. The energy available in the wind is about 1.5×10^7 MW.

Windmill is a device which converts the kinetic energy of the moving mass of air or wind into mechanical work. The windmills can be classified depending on the orientation of axis of rotation as horizontal axis windmill as shown in Figure 1.3 (a) and vertical axis windmills as shown in Figure 1.3 (b). The windmills can also be classified based on the number of blades as single bladed windmill, double bladed windmill, three bladed windmill and multi bladed windmill as shown in Figure 1.3 (c), (d) and (e).

Advantages[11]

- The wind is free and with modern technology it can be captured efficiently.
- Once the wind turbine is built the energy it produces does not cause green house gases or other pollutants.
- Although wind turbines can be very tall each takes up only a small plot of land. This means that the land below can still be used. This is especially the case in agricultural areas as farming can still continue.
- Many people find wind farms an interesting feature of the landscape.
- Remote areas that are not connected to the electricity power grid can use wind turbines to produce their own supply.
- Wind turbines have a role to play in both the developed and third world.

- Wind turbines are available in a range of sizes which means a vast range of people and businesses can use them. Single households to small towns and villages can make good use of range of wind turbines available today.

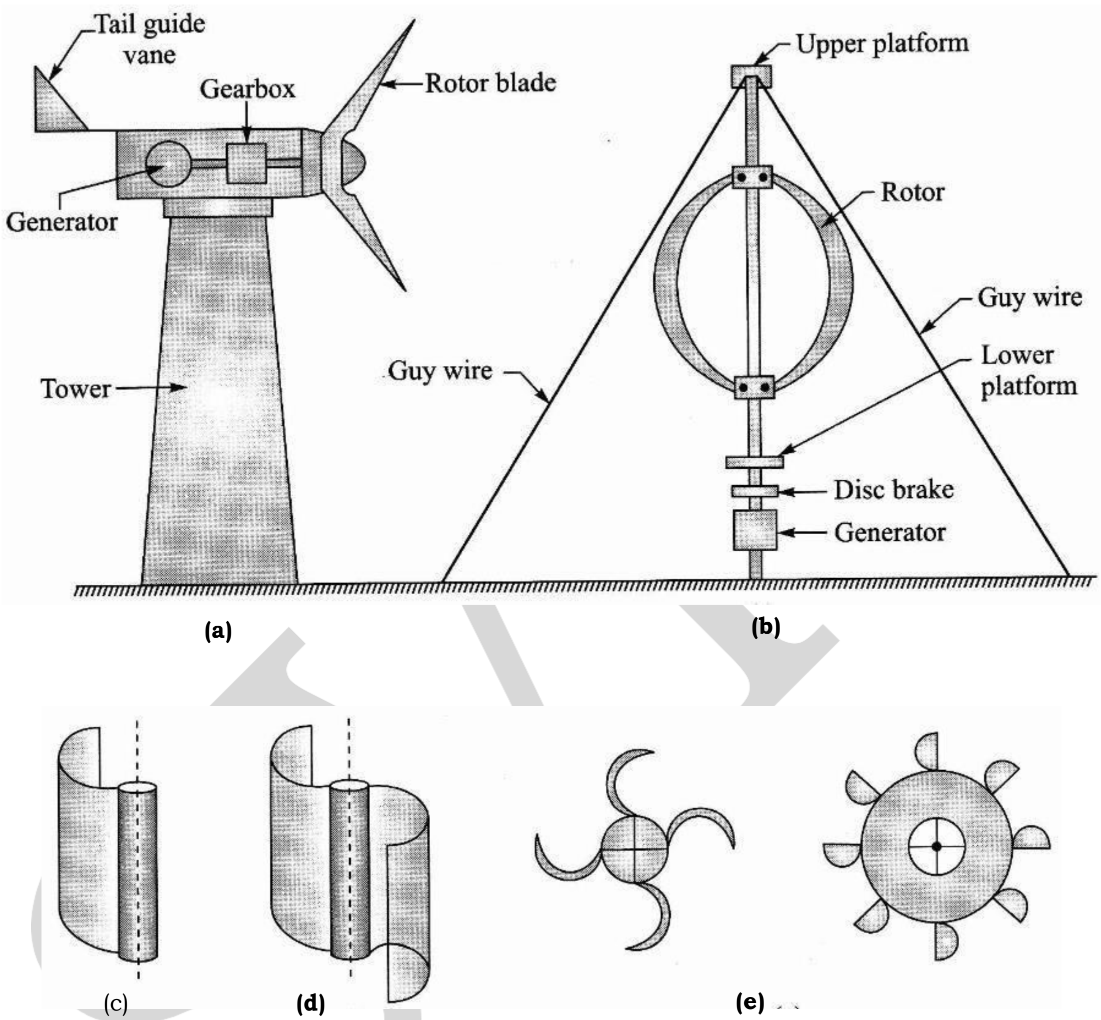


Figure 1.3 (a) Horizontal axis wind mill and (b) vertical axis wind mill (c) single bladed rotor (d) **double bladed rotor (e) multi bladed rotor**

Disadvantages

- The strength of the wind is not constant and it varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all.
- When wind turbines are being manufactured some pollution is produced. Therefore wind power does produce some pollution.

- Large wind farms are needed to provide entire communities with enough electricity. For example, the largest single turbine available today can only provide enough electricity for 475 homes, when running at full capacity. How many would be needed for a town of 100 000 people?
- Wind turbines are noisy. Each one can generate the same level of noise as a family car travelling at 70 mph.

1.4.5. Biomass Energy:

- Define biomass energy and biogas energy.
- List out advantages and disadvantages of biomass energy.

Biomass: Green plants trap solar energy through the process of 'photosynthesis' and convert it into organic matter, known as biomass.

Wood, charcoal, agricultural wastes produce the bio energy after burning; cow dung, garbage is aerobically decomposed to obtain the energy.

Dried animal dung or cattle dung cakes are used directly as fuels in rural areas but it produces smoke and has low efficiency of burning.

Biogas: biogas is formed due to *decomposition of organic waste matter*. During decomposition of organic matter, the gases such as carbon dioxide, hydrogen and hydrogen sulphide are formed.

The organic waste is generally animal dung, plant waste, etc. these waste products contain carbohydrates, proteins, which are broken down by bacteria in absence of oxygen aerobic conditions.

Advantages[12]

- Provides a non-polluting and renewable source of energy.
- Leads to improvement in the environment, and sanitation and hygiene.
- Provides a source for decentralized power generation.
- Household wastes and bio-wastes can be disposed of usefully and in a healthy manner.
- Any biodegradable matter can be used as substrate.

Disadvantages

- The process is not very attractive economically (as compared to other bio-fuels) on a large industrial scale.
- It is very difficult to enhance the efficiency of biogas systems.

- Biogas contains some gases as impurities, which are corrosive to the metal parts of internal combustion engines.
- Not feasible to locate at all the locations.

1.4.6. Ocean Temperature Difference:

- What are the various types of energy which ocean can provide? Explain the Ocean Temperature Energy Conversion (OTEC) and a working of an OTEC power plant with the help of a sketch.

The various types of energy resources which ocean can provide are as follows:

- The tides of the ocean can be used to generate electricity.
- The wind produces large waves in the ocean having high kinetic energy which can be converted into electric power.
- The temperature gradient from the surface of ocean to the great depth inside the ocean can be used to provide thermal energy to generate electricity.

The water at the ocean surface is around 25°C, while it is about 5°C at a depth of 100-200 m. Hence, these are a temperature gradient of about 20°C between these two levels and this can be used for generation of electricity by Ocean Thermal Energy Conversion (OTEC). A low boiling point liquid such as ammonia, propane or Freon can be vaporized into high pressure vapor using the heat of warm water available at the ocean surface into a boiler as shown in Figure 1.4. The liquid vapor is then used to run a turbine coupled with a generator to produce electricity. After expansion in the turbine, the liquid vapor is condensed into liquid in the condenser using cold water from the deep ocean at a temperature of about 5°C. The condensed liquid is pumped back to the boiler so as to be heated by warm water from the ocean surface. This cycle is repeated.

Advantages

- Power generation is continuous throughout the year.
- Energy is available from nature at no cost.

Disadvantages

- It has a small temperature gradient which gives a small thermodynamic efficiency.

- Capital cost is high due to necessity of heat exchanger, boiler and condenser.

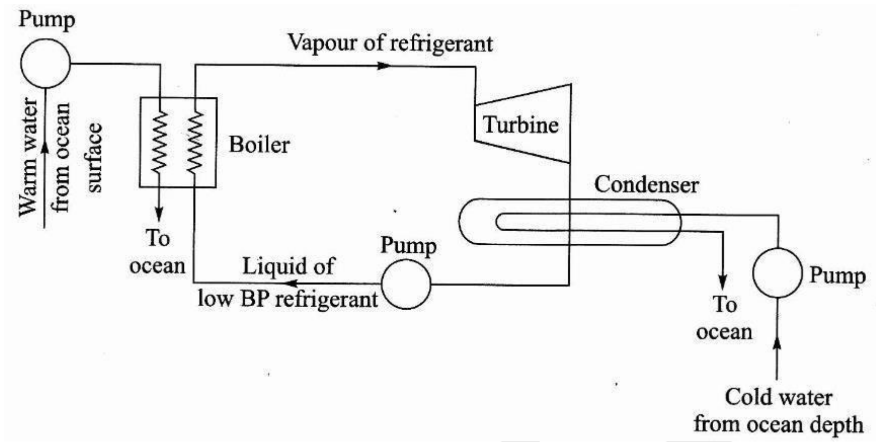


Figure 1.4 OTEC power plant.

1.4.7. <u>Tidal and waves energy</u>:

- What is tidal energy? Explain with a neat sketch the working of a tidal power plant.

Ocean waves and tides contain a large amount of both potential and kinetic energy which can be utilized for power generation. A tide is the periodical rise and fall of sea water caused principally by the interaction of the gravitational fields of the sun and the moon. The highest level of tidal water is called flood or high tide and the lowest level is called low or ebb tide. The level difference between the high and the low tide is called tidal range. The up and down movement of the tide is used for filling and emptying the tidal basin of the plant. The typical tidal plant is shown in Figure 1.5 (a) and (b). The tidal basin is filled up during high tide and it is emptied out during low tide. The flowing in and flowing out water between sea and tidal basin is used to run a turbine and generate electricity.

Advantages

- It is free from pollution.
- It is superior to hydel energy as it does not depend on water cycle.
- Tidal basin can also be used for fish farming.
- It is best suited to meet the peak power demands.

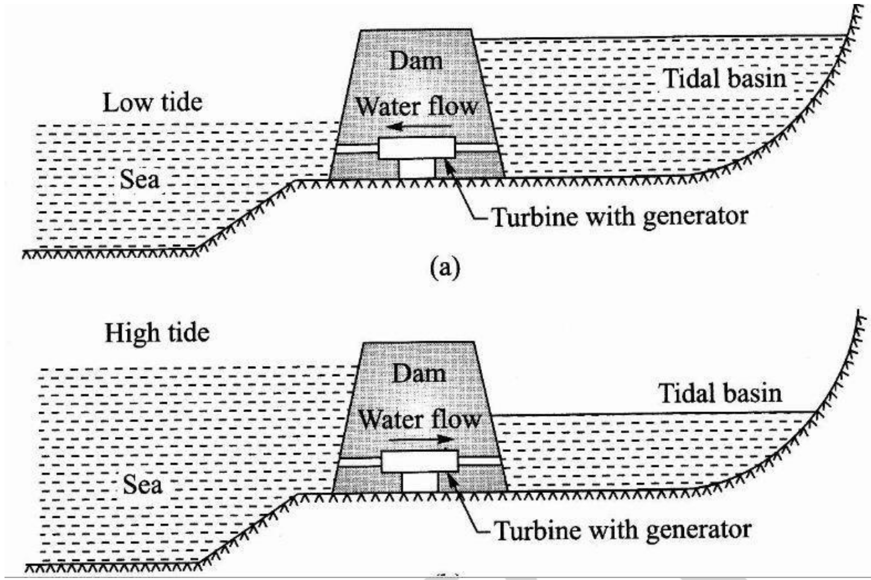


Figure 1.5 (a) Low tide tidal power plant, (b) High tide tidal power plant

Disadvantages

- It is initial investment is comparatively high.
- Limited locations are available for the construction of tidal power plant.
- Intermittent power generation due to variation in tidal cycle.

- What is wave energy? List out the difference between wave and tide

The ocean waves are caused by wind, which in turn is caused by uneven heating and subsequent cooling of earth's crust and rotation of the earth.

The most of the sea surface in the form of wind waves forms a source of energy. Floating propellers are placed in shallow waters, near the shores, and due to motion of the waves the propellers also get the motion and this kinetic energy can be used to drive turbines.

The harnessing of wave energy requires the development of special power conversion devices.

Advantages

- The wave energy is a cheap and inexhaustible source of energy.
- Wave-power devices, unlike solar or wind devices, do not use up large land masses.
- A staggered array of power devices can produce electricity, protect coastlines from the destructive action of waves, minimize erosion and even help create artificial harbors.

- It is pollution free.

Disadvantages

- Wave lacks dependability.
- There is a scarcity of accessible sites of large wave activity.
- Economic factors like capital investment, cost of maintenance, repair and replacement hinder the development.

	Tide	Waves
Definition	Tides is the rise and fall of the sea level	Waves are the energy that moves across the surface of water
Cause	Gravitational pull from the moon and sun	Wind
Intensity	Intensity of tides change depending on location and the position of the earth. Can go as high as 55 feet	Intensity of waves also changes depending on wind strength and other factors, can go as high as 90ft in air
Frequency	Occurs daily, may be twice in a day in coastal areas	Occurs regularly across bodies of water
Types	Spring tides and neap tides	Capillary waves or ripples, seas, and swells

Table 1.14 Difference between tide and wave [13]

1.4.8. Geothermal energy:

- What is geothermal energy? Explain the working principal of geothermal power plant with the help of a neat sketch.

The word geothermal is a Greek word meaning the heat of the earth. The temperature at earth's core is on the order of 4000°C. The internal heat energy available at a considerable depth below the surface of the earth is called geothermal energy. It is the heat source in the form of molten rock within the earth which is called magma and it has the temperature of about 3000°C.

A geothermal power plant is shown in Figure 1.6. The water is made to flow down through a porous layer to magma heat source where the water is converted into steam by the heat available at magma. The steam comes out through the vents of the earth surface. This steam is used to vaporize certain low boiling refrigerant. This high pressure refrigerant steam is used to run the turbine. The turbine runs a generator to produce electric power.

Advantages

- Energy is continuously available. It is more reliable.
- It has a good potential to meet the power requirement.
- Capital cost is low in comparison to nuclear and thermal power plants.

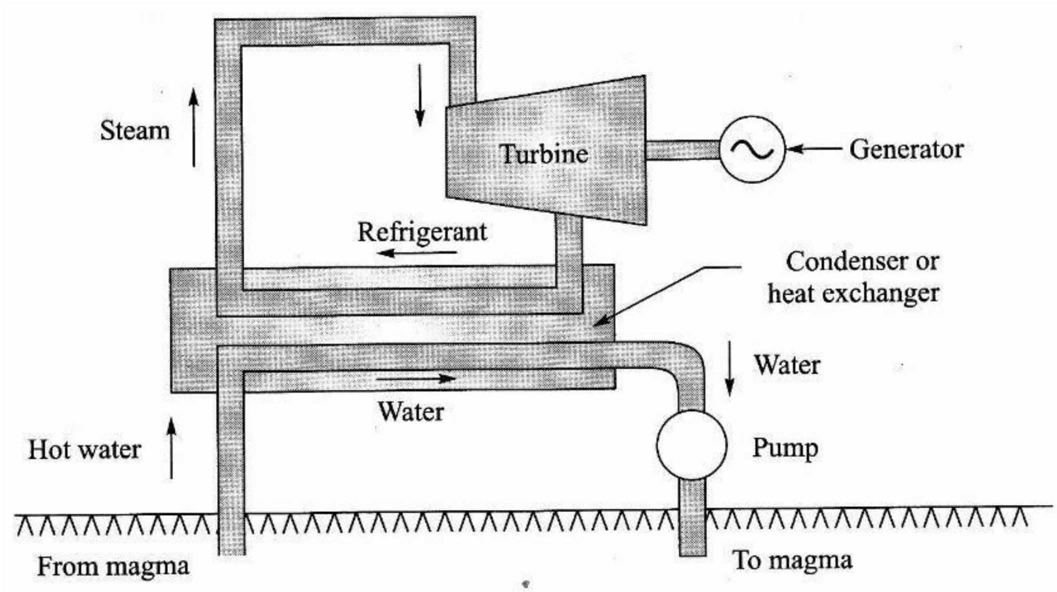


Figure 1.6 Geothermal power plant

Disadvantages

- Components of the plants are liable to be corroded.
- Gaseous effluent creates nuisance at the site for the workers.
- Gaseous effluent also creates thermal pollution to the environment.
- Ground water is likely to be polluted from gaseous effluents.

1.4.9. Oil Shale and Tar Sands:[14]

- Write a short note on Oil Shale and Tar Sands.

The term oil shale generally refers to any sedimentary rock that contains solid bituminous materials (called kerogen) that are released as petroleum-like liquids when the rock is heated in the chemical process of pyrolysis. Oil shale was formed millions of years ago by deposition of silt and organic debris on lake beds and sea bottoms. Over long periods of time, heat and pressure transformed the materials into oil shale in a process similar to the process that forms oil; however, the heat and pressure were not as great. Oil shale generally contains enough oil that it will burn without any additional processing, and it is known as “the rock that burns”.

Oil shale can be mined and processed to generate oil similar to oil pumped from conventional oil wells; however, extracting oil from oil shale is more complex than conventional oil recovery and currently is more expensive. The oil substances in oil shale are solid and cannot be pumped directly out of the ground. The oil shale must first be mined and then heated to a high temperature (a process called retorting); the resultant liquid must then be separated and collected. An alternative but currently experimental process referred to as *in situ* retorting involves heating the oil shale while it is still underground, and then pumping the resulting liquid to the surface.

Tar sands (also referred to as oil sands) are a combination of clay, sand, water, and bitumen, a heavy black viscous oil. Tar sands can be mined and processed to extract the oil-rich bitumen, which is then refined into oil. The bitumen in tar sands cannot be pumped from the ground in its natural state; instead tar sand deposits are mined, usually using strip mining or open pit techniques, or the oil is extracted by underground heating with additional upgrading.

Tar sands are mined and processed to generate oil similar to oil pumped from conventional oil wells, but extracting oil from tar sands is more complex than conventional oil recovery. Oil sands recovery processes include extraction and separation systems to separate the bitumen from the clay, sand, and water that make up the tar sands. Bitumen also requires additional upgrading before it can be refined. Because it is so viscous (thick), it also requires dilution with lighter hydrocarbons to make it transportable by pipelines.

Advantages **[15]**

Oil Shale

- Potential to produce a superior liquid-fuel product.
- Low sulfur content and therefore less air pollution.
- Abundant availability in countries such as USA that have the highest need for oil.

Tar Sands

- Large reserves available, and in countries such as Canada which are close to the countries that are major users of oil, for eg., USA.

Disadvantages

Oil Shale

- Costs of fuel production from oil shale have not yet been fully evaluated.
- Disposal of the used shale could create ecological problems. Some studies have revealed soil and groundwater contamination to various degrees by chemicals or pollutants from the oil shale tailings.

Tar Sands

- Production cannot be ramped up as quickly as conventional oil production, owing to the operational processes used in deriving oil from the sands.
- Extracting oil from tar sands entails high production costs and low net useful energy yields.
- Production of oil from tar sands has high negative environmental impacts

1.4.10. Nuclear Energy:

- What is nuclear energy? Explain the process of nuclear fusion.

The nuclear energy is released when atoms of certain unstable material split in the process of fission. A small mass of nuclear fuel such as uranium can release an enormous amount of heat energy when it undergoes fission process. One kilogram of uranium-235 can give heat energy on fission process which is equal to the heat which can be obtained by burning 4000 tons of high-grade petroleum. The uranium can be made to undergo fission process inside a nuclear reactor. The nuclear fission is a chain reaction as shown in Figure l.7.

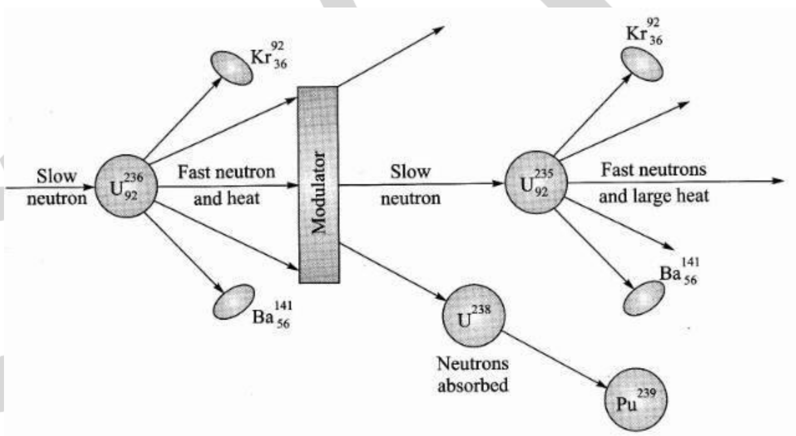


Figure 1.7 Fission process in the nuclear cell

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Solar Radiation: *Extra-Terrestrial radiation, spectral distribution of extra terrestrial radiation, solar constant, solar radiation at the earth's surface, beam, diffuse and global radiation, solar radiation data.*

Measurement of Solar Radiation: *Pyrometer, shading ring pyrheliometer, sunshine recorder, schematic diagrams and principle of working.*

2.1 Solar Energy – General Aspects:

Note:-

2.1.1 Sun and Earth

2.1.2 Sun

- It is a sphere of very hot gases and its largest members of the solar system.
- The diameter of the sun is 1.39 x 10^6 km
- The distance between the sun and earth is 1.496 x 10^8 km, it subtends an angle of only 32 minutes (0.53°) at the earth's surface.
- Sun completes one rotation in four weeks when observed from the earth. But the equator of the sun takes 27 days and Polar Regions takes about 30 days for each rotation.
- The effective black body of the sun is 5773 K.
- The heat generation is mainly due to various kinds of fusion reactions but most of the energy is released in which hydrogen (i.e. four protons) combine to form helium, the fusion reaction is as follows.

И

$$И({}_{T}H^{T}) \rightarrow {}_{'}H_e + ' ?., \ MeV$$

This energy is produced in the interior of the solar sphere and transmitted out by the radiation into the system.

Net energy radiated is given by the equation $E= \epsilon \sigma T_s^4$

Where ϵ = Emissivity of the surface, σ = Stefan's Boltzmann constant and

T_s = Effective black body surface temperature of the sun.

Earth

- It is almost round in shape and has diameter if 1.27×10^4 km.
- Its real shape is a sphere flattened at the poles and bulged in the plan normal to the poles.
- The earth's inner core is solid mass made of iron and nickel and the next outer core is melted state or iron and nickel. The outer most portions are made of rocks.
- The existence of the blue green algae indicates beginning of photosynthesis at least 3×10^9 years ago. As a result of photosynthesis, the level of O_2 and O_3 increased. In the atmosphere which block the ultra violet (UV) solar radiation coming from the sun. Half of the earth is lit by the sun at a time. It reflects one-third of the sunlight that falls on it is known as earth's albedo.
- The length of days and nights keep changing because the earth is spinning about its axis which is inclined at an angle of 23.5°.

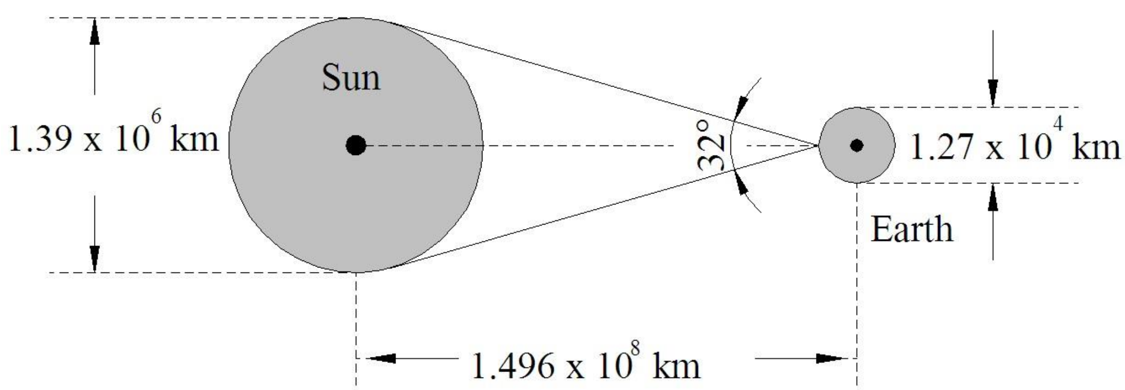

Figure 2.1 Sun and Earth in the solar system.

The amount of solar energy available on the earth's surface is 3.7×10^{20} MW, Out of which only 10^{17} Watts hits the atmosphere, and where as solar power available at the earth surface is 10^{16} watts, but for civilization the total power required is 10^{13} Watts. The atmospheric constituents affect the solar radiation by two processes called absorption and scattering. The energy radiated by the sun as electromagnetic waves of which 99 percent have wave lengths in the range of 0.2 to 0.4 μm. Solar energy reaching the top of the earth's atmosphere consists of about 8% UV radiation (short wave length, less than 0.39 μm), 46% percent visible light (0.39 μm to 0.78 μm) and remaining 46% infrared radiation (long wave length, more than 0.78 μm).

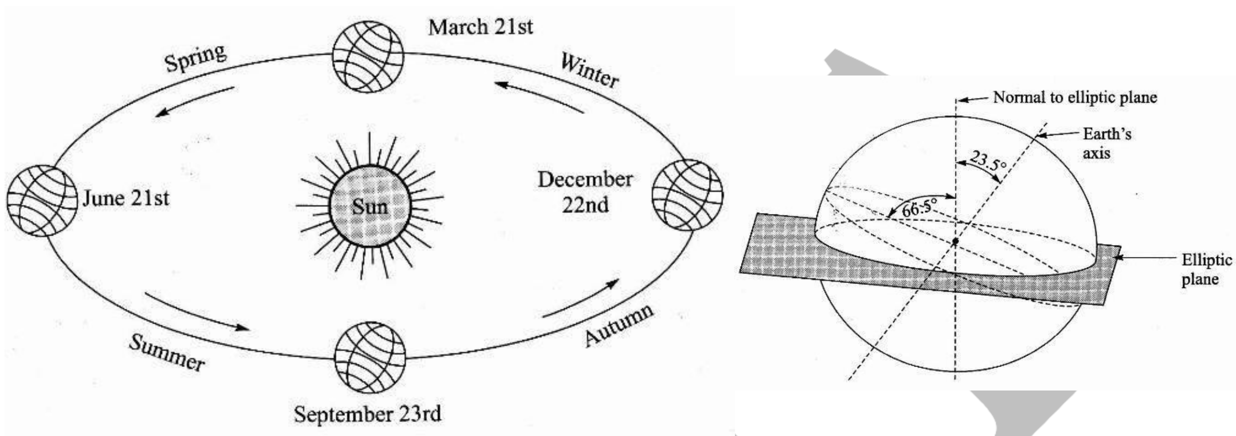

Figure 2.2 (a) Elliptical orbit of Earth's revaluation (b) Inclination of Earth's axis

The earth revolves around the sun in an elliptical orbit as shown in Figure 2.2 (a). The earth is closest to the sun on 21st March and 23rd September. The earth is farthest from the sun on 21st June and 22nd December. Therefore the intensity of solar radiation outside the earth's atmosphere reduces with distance and is dependent on the distance between earth and the sun. In fact, the intensity of solar radiation reaching outside the earth's atmosphere varies with the square of the distance between the centers of the earth and the sun. This is the reason why earth received 7% more radiation on 21st March and 23rd September compared to 21st June and 22nd December. The intensity of solar radiation keeps on attenuating as earth propagates away from the surface of the sun, but the content of wavelengths in the radiation spectrum does not change.

The earth is tilted about 23.45° with respect to the earth's orbit around the sun as shown in Figure 2.2 (b). Owing to this tilting of earth's axis, the northern hemisphere of the earth points towards the sun in the month of June and its points away from the sun in the month of December. However, earth's axis remains perpendicular to the imaginary line drawn from the earth to the sun during the months of September and March. The sun earth's distance varies during earth's rotation around the sun, there by varying the solar energy reaching its surface during revolution, which brings about sensational changes. The northern hemisphere has summer when the earth is tilting forwards the sun and winter when the earth is tilting away from the sun. In the months of September and March, both the hemispheres are at the same distance from the sun and receive equal sun shine. During the summer, the sun is higher in the sky, while the sun is lower in the sky during winter for the northern hemisphere.

2.2 Solar Radiation:

2.2.1 *Extraterrestrial solar radiation*: The intensity of sun's radiation outside the earth's atmosphere is called '*extraterrestrial*' radiation.

Extraterrestrial radiation is a measure of solar radiation that would be received in the absence of atmosphere.

2.2.2 *Terrestrial radiation*: The radiation received in the earth's atmosphere is called '*terrestrial radiation*' and is nearly 70% of extraterrestrial radiation.

[When radiation passes through the earth's atmosphere, it is subjected to the mechanism of atmospheric absorption and scattering depending on atmospheric conditions. Earth's atmosphere contains various constituents, suspended dust and solid particles, such as air molecules, oxygen, nitrogen, carbon dioxide, carbon monoxide, ozone, water vapor and dust. Therefore solar radiation or intensity of radiation is depleted during its passage through the atmosphere. The solar radiation that reaches the earth's surface after passing the earth's atmosphere is called terrestrial radiation. The propagation of solar radiation through the earth's atmosphere is shown in Figure 2.3]

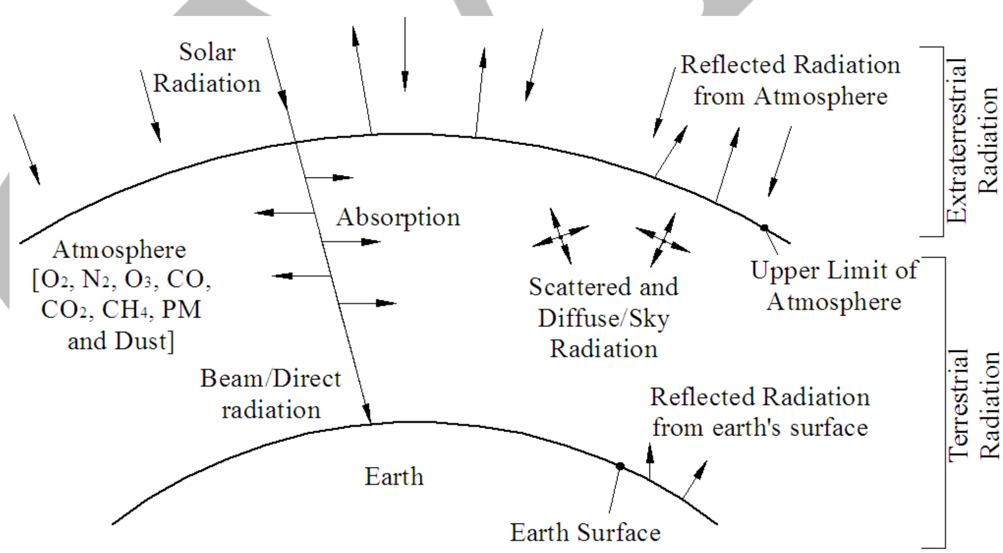

Figure 2.3 Solar Radiation

2.2.3 *Spectral distribution of extraterrestrial radiation*: light rays radiated from the sun are in the form of electromagnetic waves in infrared, visible ultraviolet frequency bands. The frequency spectrum of solar light is a graph of wave length against power density, shown in Figure 2.4

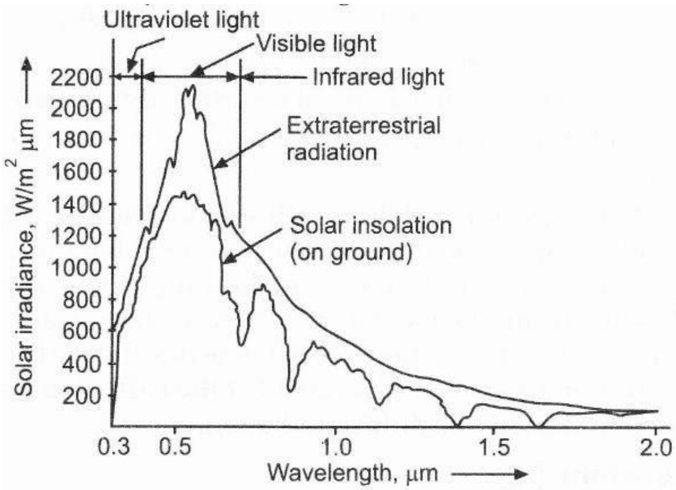

Figure 2.4 Spectral Distribution of Extraterrestrial Solar Radiation

The solar spectrum has three basic levels:

1. "*Infrared band*" with wave lengths too long for response by human eye frequency range: 40x010^{14} to 7.5 x 10^{10} Hz, wave lengths between 0.75 µm & 1.95 µm with an energy of 618 W/m^2. It constitutes 46% of solar radiation.
2. "*Visible band*" The solar radiation contains 46% visible light (band) with a frequency range: 6 x 10^{16} to 7.69 x 10^{14} Hz, with the wave length between 0.39 µm & 0.78 µm, with an energy of 640 W/m^2.
3. "*Ultraviolet band*" The solar radiation contains only 8% of UV light with a frequency range of 6 x 10^{16} to 7.5 x 10^{10} Hz, with the wave length between 0.005 µm & 0.39 µm, with energy of 95 W/m^2.

[Note: 1µm = 10^{-6} m, (µ - Micro)]

Irradiance: It is the rate at which the radiant energy is incidenting on a unit surface area. It is the measure of power density of sunlight falling per unit area and time. It is measured in W/m^2. Heat energy is measured in Joules and while Watt or Joules per second is a measure of Power.

Irradiation: It is a solar energy per unit surface area which is striking a body over a specified time. Hence it is integration of solar illumination or irradiance over specified time (usually an hour or kilowatt a day). It is measured in kilowatt-hour or kilowatt day per square meter. For example, if irradiance is 20 kW/m^2 for 5 hours, irradiance is 20 x 5 = 100 kW-hr/m^2.

2.2.4 *Beam/Direct Radiation (I_b)*: Solar radiation received on the surface of the earth without change in direction is known as beam/direct radiation.

2.2.5 *Diffuse/Sky Radiation (I_d)*: The solar radiation received from the sun after its direction has been changed by reflection and scattering by atmosphere is known as diffuse/sky radiation.

2.2.6 *Total/Global Radiation* (I_T/I_g): The sum of beam and diffuse radiation intercepted at the surface of earth per unit area of location is known as total/global radiation, it is also known as '*insolation*'.

2.2.7 *Air mass (m)*: Air mass is the ratio of the path length through the atmosphere which the solar beam actually traverses up to earth's surface to the vertical path length through the atmosphere.

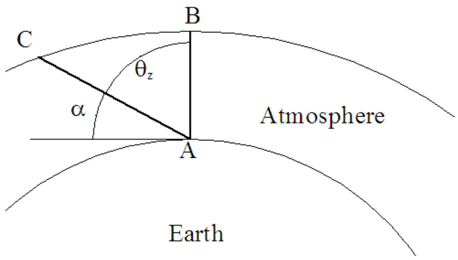

Figure 2.5 Concept of Air mass

2.2.8 *Solar Constant* (I_{sc}): It is defined as the energy received from the sun per unit time on a unit surface area perpendicular to the direction of propagation of solar radiation at the top of earth's atmosphere when the earth is at its mean distance from the sun. The value of solar constant is taken as 1.353 kW/m^2. (The standard value of solar constant based on the experimental measurements is 1.376 kW/m^2 with accuracy of ±1.5%)

2.3 Solar Radiation at the earth's surface:

Solar radiation received at the earth's surface is an attenuated form because it is subjected to the mechanisms of absorption and scattering as it passes through the atmosphere (Figure 2.3). Absorption occurs primarily because of the presence of ozone and water vapor in the atmosphere, and to a lesser extent due to other gases (like CO, CO_2, NO_2, O_2, CH_4, O_3) Particulate Matter and dust particles. It results in increase in internal energy of the atmosphere. On the other hand, scattering occurs due to all gaseous molecules as well as particulate matter in the atmosphere. The scattered radiation is redistributed in all directions, some going back into the space and some reaching the earth's surface.

The atmosphere at any location on the earth's surface is often classified into two broad types an atmosphere without clouds and atmosphere with clouds. In the former case, the sky is cloudless everywhere, while in the later, the sky is partly or fully covered by clouds. The mechanisms of absorption and scattering are similar in both types of atmosphere. However it is obvious that less attenuation takes place in a cloudless sky. Consequently maximum radiation is received on the earth's surface under the conditions of cloudless sky.

In general the intensity of diffuse radiation coming from various directions in the sky is not uniform. The diffuse radiation is therefore said to be anisotropic in nature. However in many situations, the intensity from all directions tends to be reasonably uniform. It is then modeled as being perfectly uniform as is said to be isotropic in nature.

Extensive studies have been made on mechanisms of absorption and scattering, and on the determination of attenuation coefficients for various substances. Nevertheless, it is in general not possible to predict, to a reasonable degree of accuracy, the variation with time of the beam and diffuse radiation with might be expected at a specified location on the earth's surface.

2.3.1 ***Depletion of Solar radiation*:**

The earth's atmosphere contains various gaseous constituents, suspended dust and other minute solid and liquid particulate matter. These are air molecules, ozone, oxygen, nitrogen, carbon dioxide, carbon monoxide, water vapor, dust, and water droplets. Therefore solar radiation is depleted during its passage through the atmosphere. Different molecules to different things as explained below

- ***Absorption***: Selective absorption of various wavelengths occurs by different molecules. The absorbed radiation increases the energy of the absorbing molecules, thus raising their temperatures.
  - (a) Nitrogen, molecular oxygen and other atmospheric gases absorb the X-rays and extreme ultraviolet radiations.
  - (b) Ozone absorbs a significant amount of ultraviolet radiation in the range (λ < 0.38 μm).
  - (c) Water vapor (H_2O) and carbon dioxide absorb almost completely the infrared radiation in the range (λ > 2.3 μm) and deplete to some extent the near infrared radiation below this range.
  - (d) Dust particles and air molecules also absorb a part of solar radiant energy, irrespective of wavelength.

- ***Scattering***: Scattering by dust particles and air molecules (or gaseous particles of different sizes) involves redistribution of incident energy. A part of the scattered radiation is lost (reflected back) to space and the remaining is directed downwards to the earth's surface from different directions as diffuse radiation. It is the scattered sunlight that makes the sky blue. Without the atmosphere and its ability to scatter sunlight, the sky would appear black as it does on the moon.

2.4 Solar Radiation Data

Most radiation data is measured for horizontal surfaces. A typical daily record of the global and diffuse radiation flux measured on a clear day is shown in Figure 2.6. It is seen that a fairly, smooth variation with the maximum occurring around noon is obtained on a clear day. In contrast, an irregular variation with many peaks and valleys may be obtained on a cloudy day. We will use the symbols I_g and I_d to represent the instantaneous values of the global and diffuse flux plotted in Figure 2.6 and express these quantities in W/m^2. Since solar radiation fluxes do not normally change rapidly with time, we will use the same symbols I_g and I_d to represent hourly values also. These quantities expressed in $kW\text{-}h/m^2\text{-}h$ or $kJ/m^2\text{-}h$. The shaded area below the graphs represent global and diffuse flux incident over a whole day. We will use the symbols H_g and H_d to represent these qualities and express them in $kW\text{-}h/m^2\text{-}day$ of $kJ/m^2\text{-}day$.

Solar radiation flux is some times reported in langleys per hour per day (1 langley = 1 cal/cm^2 = 1.163×10^{-2} kWh/m^2). The 'langley' has been adopted in honor of Samuel Langley who made the first measurement of the spectral distribution of the sun.

A solar designer primarily interested in average values for a location. The averaging is usually done over all days of a month and indicated by a bar over the symbol. Tabulations showing the hourly variation of global and diffuse radiation ($\bar{I}_g$, $\bar{I}_d$), the amount received per day ($\bar{H}_g$, $\bar{H}_d$) and sunshine hours per day ($\bar{n}$) are available for many locations in India. The table 2.1 to 2.4 shows the data for two locations of India i.e. New Delhi and Mumbai.

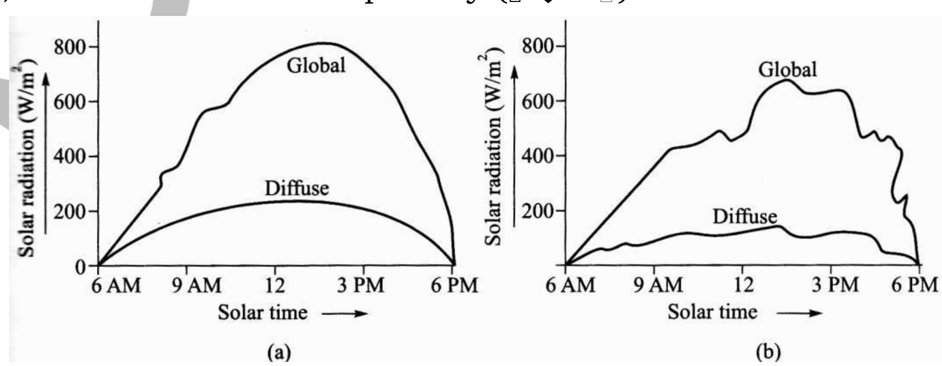

Figure 2.6 Daily Variation of Global and Diffuse radiation data measured on a horizontal surface (a) Clear sky (b) cloudy sky

Location: New Delhi (28°35' N, 77°12' E)

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	kWh/m²-day	h
J	0.000	0.004	0.096	0.271	0.433	0.556	0.618	0.615	0.552	0.430	0.268	0.099	0.005	0.000	3.987	7.6
F	0.000	0.020	0.163	0.364	0.540	0.670	0.727	0.728	0.659	0.534	0.358	0.165	0.021	0.000	5.001	9.0
M	0.001	0.066	0.260	0.475	0.655	0.781	0.845	0.844	0.769	0.635	0.458	0.249	0.064	0.001	6.138	8.2
A	0.010	0.130	0.339	0.554	0.727	0.848	0.910	0.903	0.833	0.699	0.523	0.318	0.122	0.010	6.935	8.6
M	0.030	0.177	0.383	0.581	0.746	0.865	0.925	0.920	0.844	0.719	0.547	0.352	0.158	0.027	7.287	8.0
J	0.036	0.164	0.339	0.510	0.657	0.757	0.809	0.813	0.750	0.639	0.483	0.318	0.159	0.036	6.544	5.9
J	0.026	0.130	0.275	0.425	0.549	0.640	0.672	0.671	0.606	0.518	0.412	0.273	0.141	0.032	5.334	5.8
A	0.012	0.101	0.243	0.392	0.512	0.607	0.640	0.659	0.595	0.510	0.392	0.255	0.107	0.013	5.053	5.6
S	0.003	0.079	0.248	0.431	0.587	0.698	0.757	0.747	0.689	0.571	0.417	0.244	0.074	0.003	5.602	7.0
O	0.000	0.036	0.202	0.406	0.581	0.701	0.764	0.758	0.692	0.569	0.391	0.191	0.033	0.000	5.355	8.8
N	0.000	0.009	0.128	0.319	0.495	0.620	0.685	0.680	0.613	0.490	0.315	0.125	0.010	0.000	4.523	9.2
D	0.000	0.003	0.085	0.259	0.425	0.543	0.605	0.605	0.538	0.418	0.255	0.086	0.003	0.000	3.843	8.0

Table 2.1 Monthly average hourly global radiation �, daily global radiation �, and sunshine hours �

N.B. Time indicated is LAT. Value of given for a particular time corresponds to the radiation (in kWh/m²-h) incident on a horizontal surface during the one hour preceding the time. Multiply by 3600 to obtain an hourly value (in kJ/m²-h)

Location: New Delhi (28°35' N, 77°12' E)

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	kWh/m²-day
J	0.000	0.003	0.051	0.103	0.140	0.160	0.174	0.172	0.162	0.137	0.100	0.051	0.003	0.000	1.240
F	0.000	0.013	0.076	0.126	0.159	0.183	0.191	0.190	0.180	0.160	0.125	0.075	0.013	0.000	1.474
M	0.001	0.043	0.113	0.159	0.189	0.210	0.222	0.226	0.215	0.197	0.163	0.113	0.041	0.001	1.861
A	0.009	0.083	0.153	0.202	0.236	0.262	0.274	0.279	0.274	0.250	0.212	0.156	0.079	0.008	2.473
M	0.027	0.114	0.190	0.244	0.279	0.303	0.315	0.318	0.308	0.286	0.247	0.189	0.107	0.022	2.922
J	0.033	0.124	0.215	0.286	0.342	0.382	0.399	0.299	0.377	0.340	0.279	0.203	0.114	0.028	3.540
J	0.023	0.096	0.178	0.257	0.316	0.358	0.372	0.365	0.333	0.291	0.241	0.174	0.101	0.023	3.135
A	0.009	0.074	0.153	0.224	0.277	0.317	0.334	0.331	0.302	0.265	0.210	0.149	0.075	0.010	2.727
S	0.002	0.053	0.123	0.178	0.222	0.256	0.269	0.263	0.248	0.217	0.167	0.118	0.048	0.002	2.152
O	0.000	0.026	0.087	0.128	0.154	0.169	0.179	0.177	0.169	0.154	0.126	0.083	0.021	0.001	1.465
N	0.000	0.007	0.057	0.099	0.122	0.137	0.145	0.146	0.142	0.124	0.099	0.055	0.006	0.000	1.141
D	0.000	0.002	0.045	0.092	0.123	0.144	0.155	0.156	0.147	0.125	0.092	0.043	0.002	0.000	1.117

Table 2.2 Monthly average hourly diffuse radiation �, daily global radiation �

N.B. Time indicated is LAT. Value of given for a particular time corresponds to the radiation (in kWh/m²-h) incident on a horizontal surface during the one hour preceding the time. Multiply by 3600 to obtain an hourly value (in kJ/m²-h)

Location: Mumbai (19°07' N, 72°51' E)

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	kWh/m²-day	h
J	0.000	0.018	0.154	0.358	0.528	0.660	0.735	0.746	0.685	0.560	0.383	0.175	0.022	0.000	5.031	9.3
F	0.000	0.032	0.198	0.407	0.599	0.737	0.823	0.835	0.769	0.644	0.456	0.230	0.042	0.000	5.755	9.7
M	0.001	0.062	0.252	0.465	0.654	0.801	0.888	0.901	0.832	0.704	0.513	0.281	0.072	0.001	6.448	9.5
A	0.004	0.095	0.288	0.492	0.695	0.845	0.937	0.955	0.893	0.759	0.563	0.333	0.113	0.005	6.991	9.6
M	0.012	0.124	0.294	0.489	0.710	0.864	0.952	0.962	0.899	0.768	0.578	0.360	0.150	0.017	7.262	9.3
J	0.011	0.093	0.217	0.364	0.508	0.605	0.666	0.678	0.638	0.548	0.412	0.253	0.108	0.015	5.177	5.6
J	0.007	0.069	0.168	0.286	0.399	0.498	0.541	0.555	0.515	0.433	0.325	0.199	0.082	0.009	4.061	2.4
A	0.003	0.057	0.162	0.290	0.407	0.478	0.554	0.540	0.493	0.410	0.293	0.176	0.066	0.005	3.976	2.4
S	0.001	0.051	0.184	0.329	0.466	0.576	0.650	0.693	0.669	0.571	0.401	0.222	0.068	0.002	4.878	5.2
O	0.000	0.038	0.195	0.382	0.550	0.663	0.749	0.773	0.733	0.616	0.429	0.222	0.050	0.001	5.443	8.2
N	0.000	0.022	0.166	0.367	0.547	0.669	0.731	0.741	0.741	0.545	0.371	0.174	0.024	0.000	5.074	8.9
D	0.000	0.013	0.142	0.342	0.517	0.647	0.717	0.719	0.719	0.524	0.353	0.155	0.017	0.000	4.794	8.9

Table 2.3 Monthly average hourly global radiation �, daily global radiation �, and sunshine hours �

N.B. Time indicated is LAT. Value of given for a particular time corresponds to the radiation (in kWh/m²-h) incident on a horizontal surface during the one hour preceding the time. Multiply by 3600 to obtain an hourly value (in kJ/m²-h)

Location: New Delhi (28°35’ N, 77°12’ E)

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	kWh/m²-day
J	0.000	0.010	0.064	0.104	0.133	0.155	0.164	0.161	0.150	0.133	0.107	0.070	0.012	0.000	1.279
F	0.000	0.020	0.083	0.127	0.161	0.178	0.184	0.177	0.161	0.143	0.121	0.083	0.023	0.000	1.467
M	0.001	0.041	0.109	0.162	0.192	0.209	0.207	0.202	0.189	0.172	0.146	0.104	0.040	0.000	1.776
A	0.002	0.067	0.145	0.203	0.237	0.254	0.252	0.242	0.222	0.201	0.174	0.130	0.062	0.002	2.187
M	0.009	0.087	0.172	0.234	0.268	0.280	0.281	0.273	0.259	0.236	0.199	0.153	0.086	0.011	2.508
J	0.010	0.076	0.164	0.243	0.304	0.339	0.367	0.359	0.336	0.301	0.244	0.166	0.079	0.011	2.969
J	0.008	0.059	0.147	0.234	0.309	0.373	0.396	0.404	0.368	0.316	0.244	0.160	0.067	0.008	3.065
A	0.001	0.048	0.145	0.249	0.333	0.377	0.432	0.414	0.380	0.327	0.233	0.143	0.060	0.002	3.156
S	0.001	0.045	0.144	0.227	0.288	0.345	0.366	0.359	0.339	0.296	0.224	0.139	0.049	0.001	2.860
O	0.000	0.025	0.115	0.167	0.207	0.232	0.244	0.249	0.220	0.190	0.147	0.096	0.031	0.000	1.982
N	0.000	0.012	0.067	0.101	0.124	0.142	0.148	0.144	0.142	0.128	0.103	0.065	0.012	0.000	1.193
D	0.000	0.009	0.061	0.092	0.113	0.129	0.137	0.139	0.133	0.119	0.098	0.061	0.010	0.000	1.106

Table 2.4 Monthly average hourly diffuse radiation �, daily global radiation �

N.B. Time indicated is LAT. Value of � given for a particular time corresponds to the radiation (in kWh/m²-h) incident on a horizontal surface during the one hour preceding the time. Multiply by 3600 to obtain an hourly value (in kJ/m²-h)

2.5 Instruments for measuring Solar Radiation and Sunshine

The instruments used for measurement will now be described. The solar radiation flux is usually measured with the help of pyranometer or pyrheliometer.

2.5.1 *Pyranometer*:

A pyranometer is an instrument which measures either global or diffuse radiation falling on a horizontal surface. A sketch of one type of pyranometer as installed for the measurement of global radiation is shown in Figure 2.7. Basically pyranometer consists of a black surface which heats up when exposed to solar radiation. Its temperature increases until the rate of heat gain by solar radiation is equal to the rate of heat loss by conduction, convection and re-radiation. The hot junctions of a thermopile are attached to the black surface, while the cold junctions are located under a guard plate so that they do not receive radiation directly. As a result emf is generated, recorded or integrated over a period of time and is a measure of global radiation.

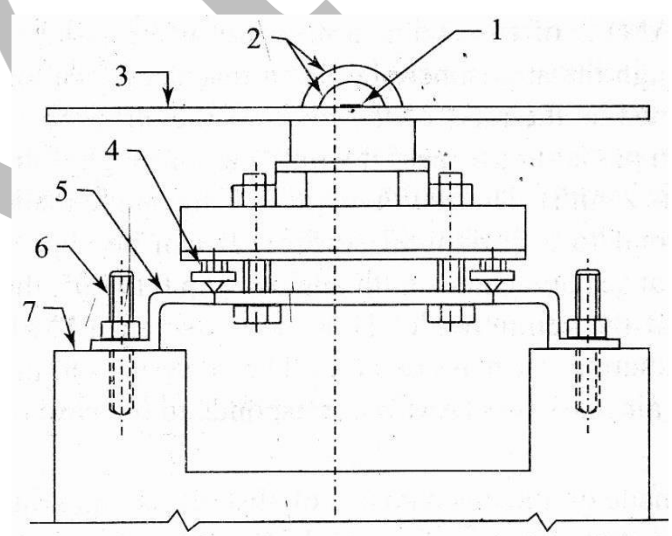

Figure 2.7 Pyranometer for measuring global radiation

(1) Black surface, (2) Glass domes, (3) Guard plate, (4) Leveling screws, (5) Mounting plate, (6) Bolts, (7) Platform

The pyranometer shown in Figure 2.7 is used commonly in India. It has a hot junction arranged in the form of horizontal disc of diameter 25 mm and coated with a special black lacquer having a very high absorptivity in the solar wavelength region. The disc is placed on the large diameter guard plate which may be horizontal or slopping. Two concentrating hemispheres, 30 mm and 50 mm in diameter respectively, made of optical glass having excellent transmission characteristics, are used to protect the disc surface from the weather. An accuracy of about ±2% can be obtained with the instrument.

2.5.2 ***Shading Ring Pyranometer***:

The pyranometer can also be used for the measurement of diffuse radiation. This is done by mounting it at the centre of a semicircular shading ring. The shading ring is fixed in such a way that its plane is parallel to the plane of the path of the sun's daily movement across the sky and its shades the thermopile element and two glass domes of the pyranometer at all times from direct sunshine. Consequently, the pyranometer measures only the diffuse radiation received from the sky.

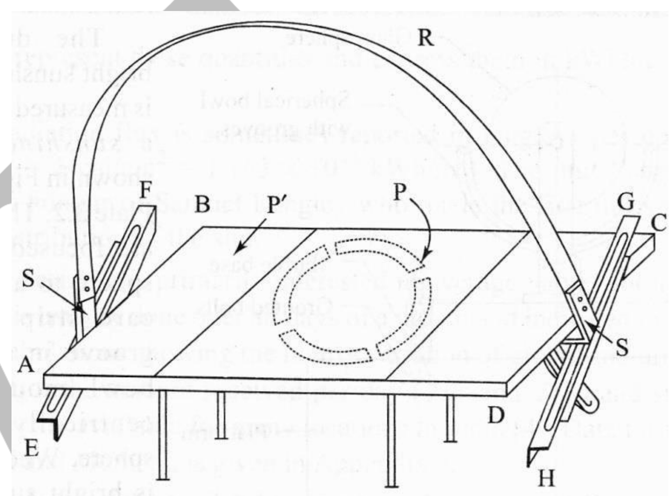

Figure 2.8 Shading ring for measurement of diffuse radiation

The construction of one type of shading ring is as shown in Figure 2.8. ABCD is a horizontal rectangular frame 35 cm X 80 cm with its long sides in east-west direction. To the side AB and CD of the frame are provided two angle-iron arms, EF and GH, 70 cm long with slots along their length, carrying sliders, SS on which is mounted the semicircular shading ring R. The arms are pivoted about a horizontal axis which passes through the centre of the rectangular frame and can be adjusted at an angle to the horizontal equal to the latitude of the station. The movement of the ring up and down the arms allows for changes in the sun's declination. The shading ring is of aluminum, 50 mm broad and is bent to a radius of 450 mm. the inner surface of the ring is painted dull black. To the bottom of the frame ABCD is fixed a thick metal plate P with a circular slot so that the frame, when fixed on a masonry platform with nuts and bolts, can be adjusted in its proper position by rotation about vertical axis. To the top of the frame is fitted another thick metal plate p′ on which the pyranometer is mounted.

2.5.3 ***Pyrheliometer***:

A pyrheliometer is an instrument which measures beam radiation falling on a surface normal to the sun's rays. In contrast to a pyranometer, the black absorber plate (with the hot junctions of thermopile attached to it) is located at the base of a collimating tube as shown in Figure 2.9. The tube is aligned with the direction of the sun's rays with the help of two-axis tracking mechanism and the alignment indicator. Thus the black plate receives only beam radiation & a small amount of diffuse radiation falling with in acceptance angle of the instrument.

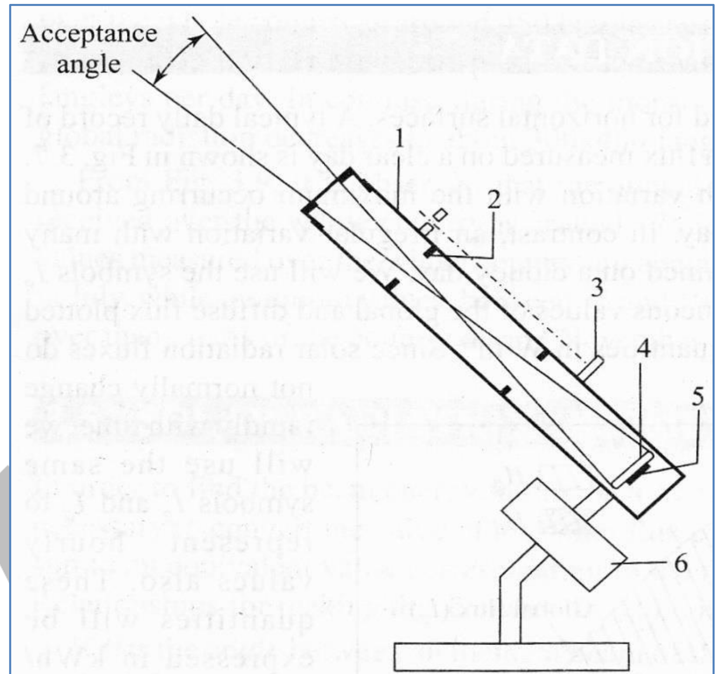

Figure 2.9 Pyrheliometer for measuring beam radiation

(1) Tube blackened on inside surface, (2) Baffle,
(3) Alignment indicator, (4) Black absorber plate,
(5) Thermopile junctions, (6) two-axis tracking mechanism

2.5.4 ***Sunshine recorder***:

The duration of bright sunshine in a day is measured by means of a sunshine recorder as shown in Figure 2.10. The sun's rays are focused by a glass sphere to a point on a card strip held in a grove in a spherical bowl mounted concentrically with the sphere. Whenever there is a bright sunshine, the image formed is intense enough to burn a spot on the card strip. Through the day as the sun moves across the sky, the

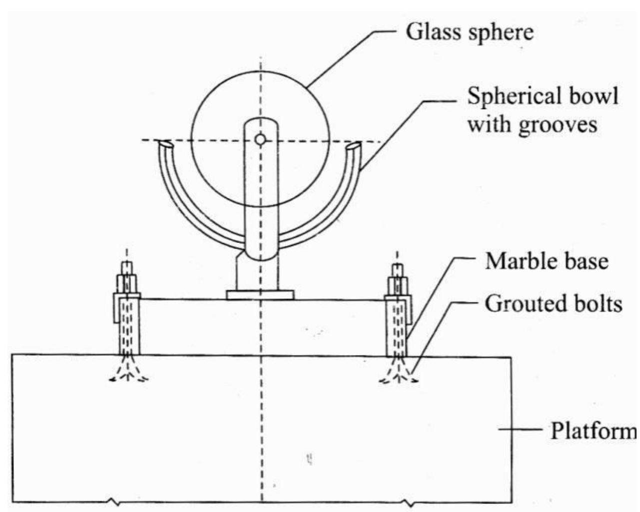

Figure 2.10 Sunshine recorder

image moves along the strip. Thus, a burnt trace whose length is proportional to the duration of sunshine is obtained on the strip.