Part A

Unit - I:

Introduction: ***energy source, India's production and reserves of*** *commercial energy sources, need for non-conventional energy sources, energy alternatives, solar, thermal, photovoltaic, water power, wind, bio-mass, ocean temperature difference, tidal and waves, geothermal, tar-sands and oil shale, nuclear (brief description); advantages and disadvantages, comparison (Qualitative and Quantitative)*

1.0 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.

For easy understanding the per capita energy consumption of the selected nations is tabulated below

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

Per capita energy consumption for selected nations

NOTE:-BTU-British thermal units, A "British thermal unit" (Btu) are 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 one can easily capita energy consumption is 16.68 times neighbor china is also 4 times greater.

BTU conversion factors

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

1.1 Energy Source:

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.

States/UT	Hydro		Thermal		Nuclear		New & renewable **		Total		Growth
	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**

India's production and reserves of commercial energy sources

**:- 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

1.2.1 Indian Energy Scenario

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

Power plant	Year	8th Plan	9th Plan	10th Plan	total
	(1991)	(1997)	(2001)	(2007)	
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

Indian generation capacity (in MW) as planned

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	

Total installed capacity as per sector 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**

Total installed capacity as per the fuel type in India

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

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

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

Few Thermal Power Stations installed in India

Wind energy: The total wind energy potential is estimated in India as 1,51,918 MW 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.

Table shows few installed wind mills in India, and 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

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**

State wise wind mill distribution in India

Hydel Energy: The total hydel energy potential is estimated in India as 1,48,701 MW, 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 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

Few Hydel Power Stations installed in India

2. 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.

3. Classification of 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

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
These are likely to be depleted, that is, these have limited availability	These are no depletable or may be
Coal, petrol, diesel, nuclear fuels, CNG and LPG are conventional energy resources	Available in vast quantities Solar, wind, tidal, geothermal and biogas are non-conventional energy resources.

Comparison between conventional and non-conventional resources

Renewable and non-renewable energy resources

- **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.
- **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

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

3. Need for non-conventional energy sources

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

- There is ever-increasing use of fossil fuels
- Depletion of fossil fuels is taking place at a rapid pace.
- 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.

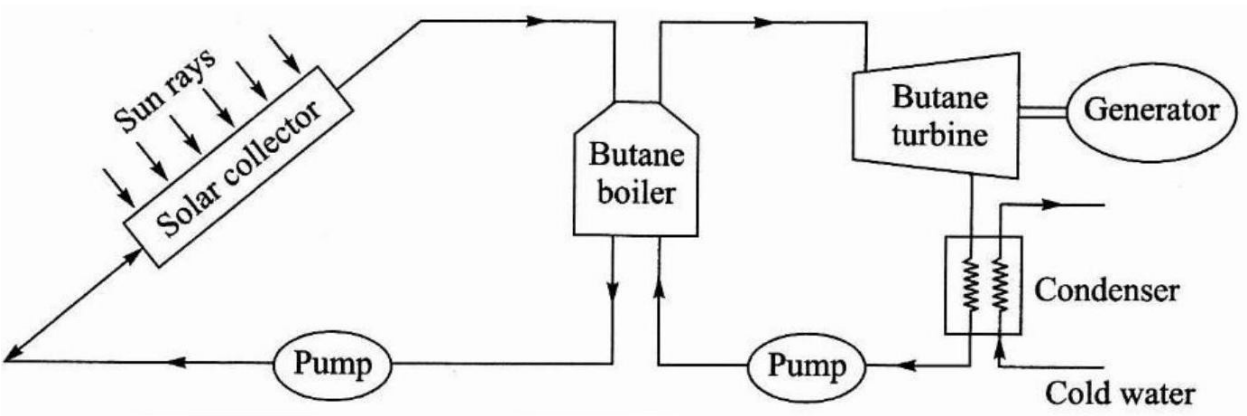
1.4 Energy alternatives/types of energy resource

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 x 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. 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.



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:

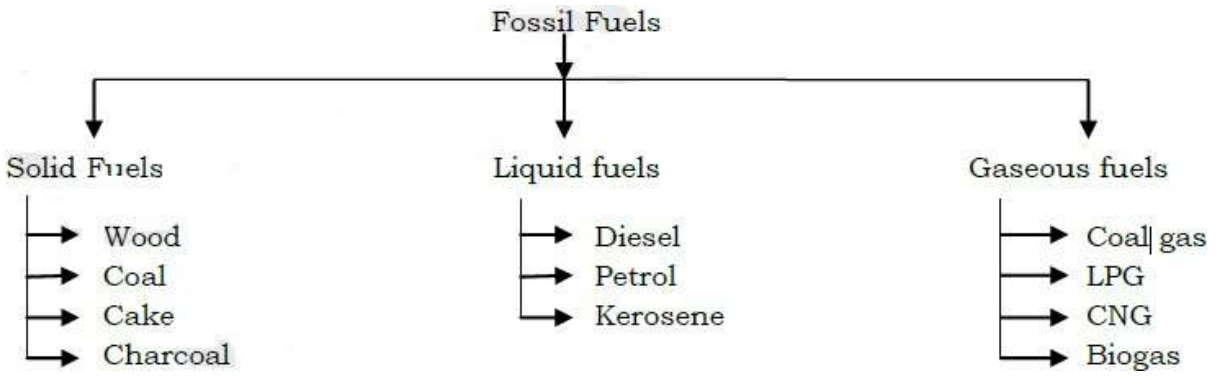
- It is available only during daytimes and clear days.
- Low efficiency.
- It requires very large area to entrap appreciable solar energy for the generation of an economical amount of electricity.

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. <u>Thermal Energy</u>:

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

- 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.

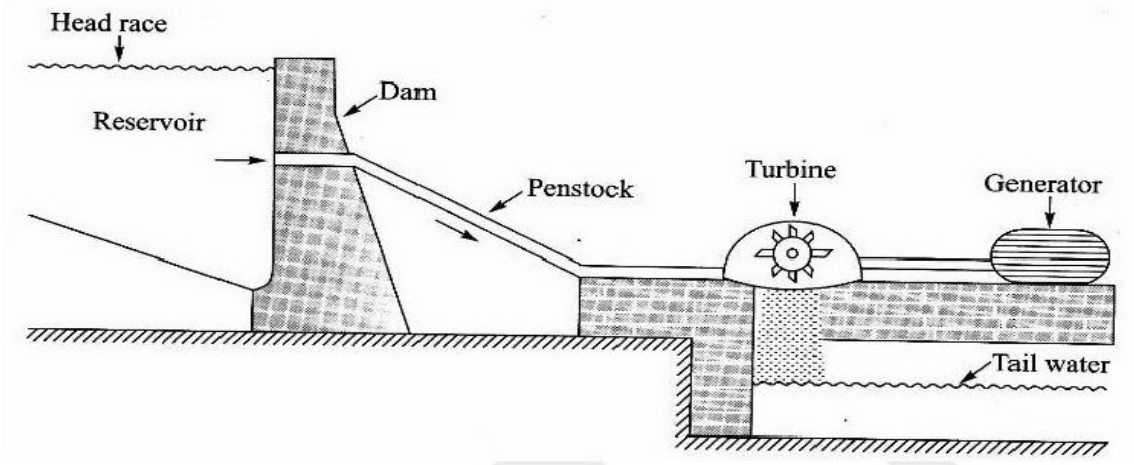
Disadvantages

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

3. <u>Water (hydro/hydel) Energy</u>:

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. 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

- 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.

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.

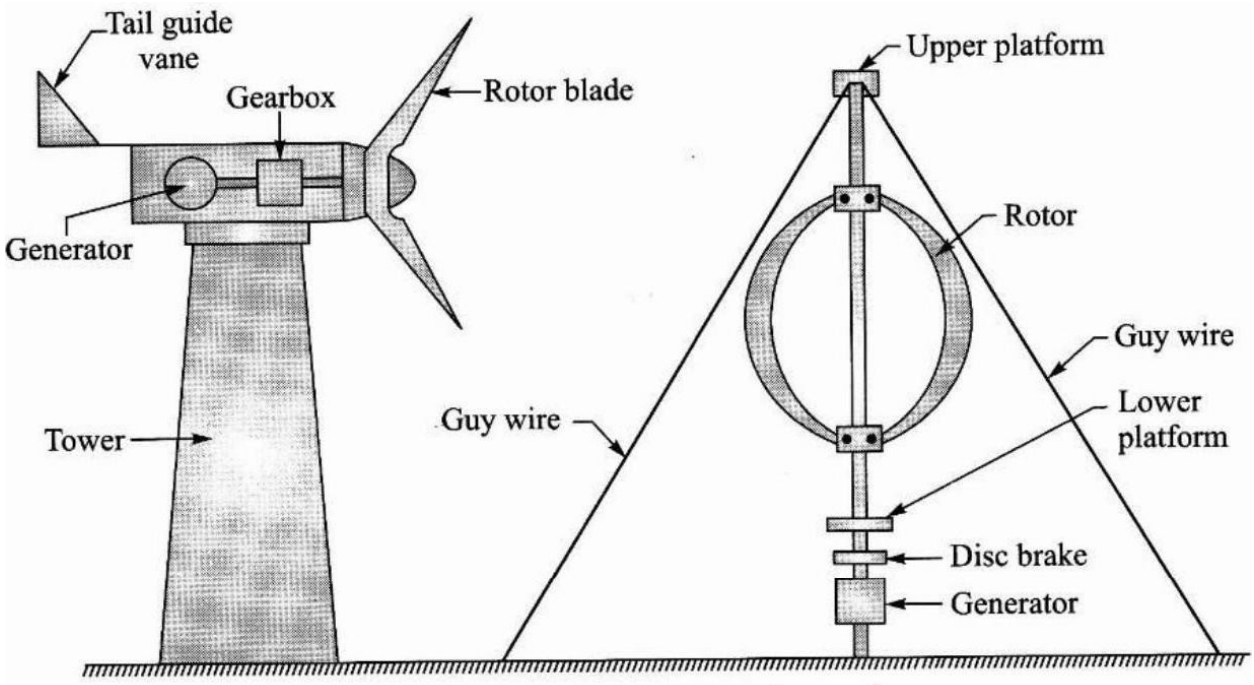
4. Wind Energy:

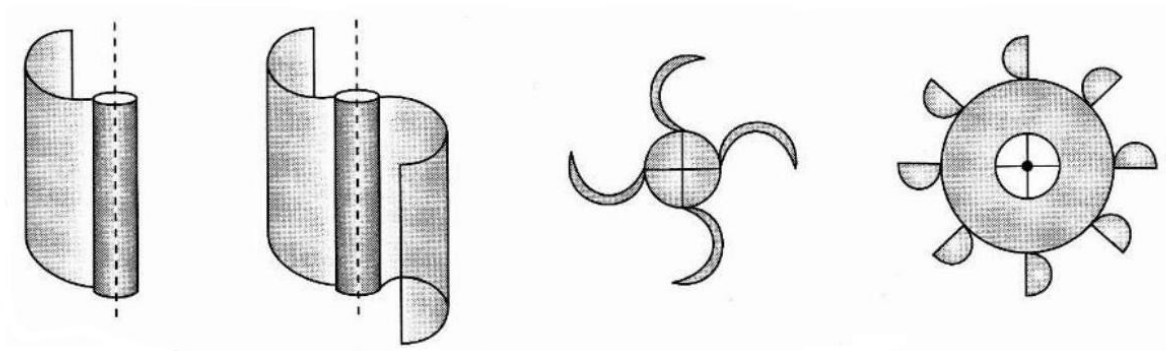
Wind is induced in atmosphere by uneven heating of earth‟s surface by the sun. The wind energy is associated with the movement of large masses of air from cold to hot regions. The motion results from uneven heating of atmosphere by sun, thereby creating, temperature, density and pressure differences. 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

Advantages

- 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.





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.

5. 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

- 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.

6. Ocean Temperature Difference:

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.

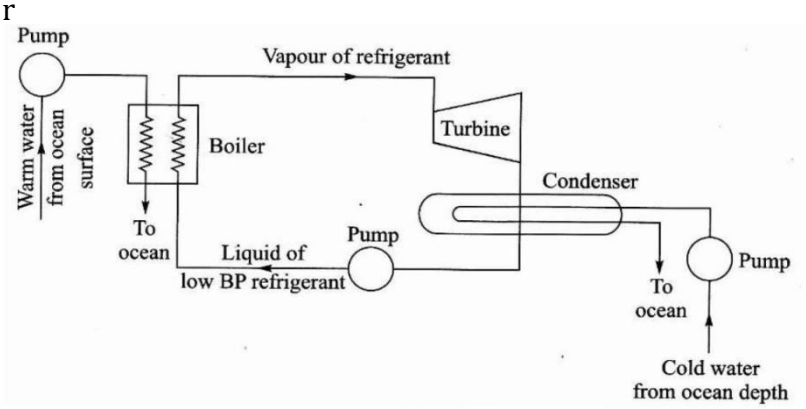
The water at the ocean surface is around 25°C, while it is about 5°C at a depth of 100-200 m. Hence, these are a temperature gradient of about 20°C between these two levels and this can be used for generation of electricity by Ocean Thermal Energy Conversion (OTEC). A low boiling point liquid such as 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 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



OTEC power plant.

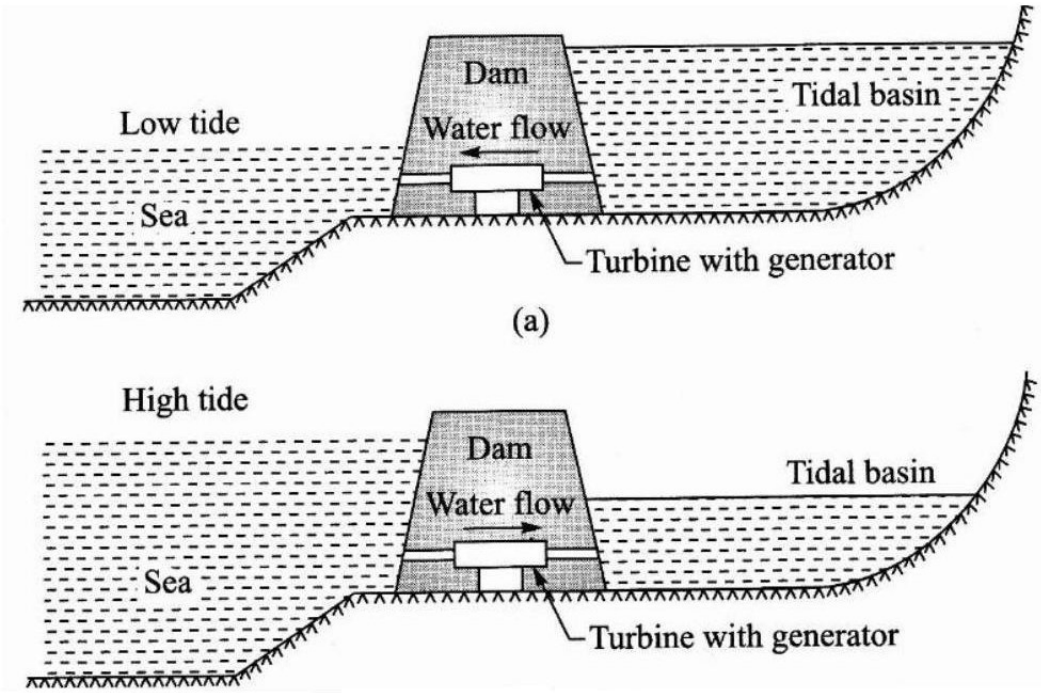
1.4.7. **<u>Tidal and waves energy</u>:**

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 (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.



(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.

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

Difference between tide and wave

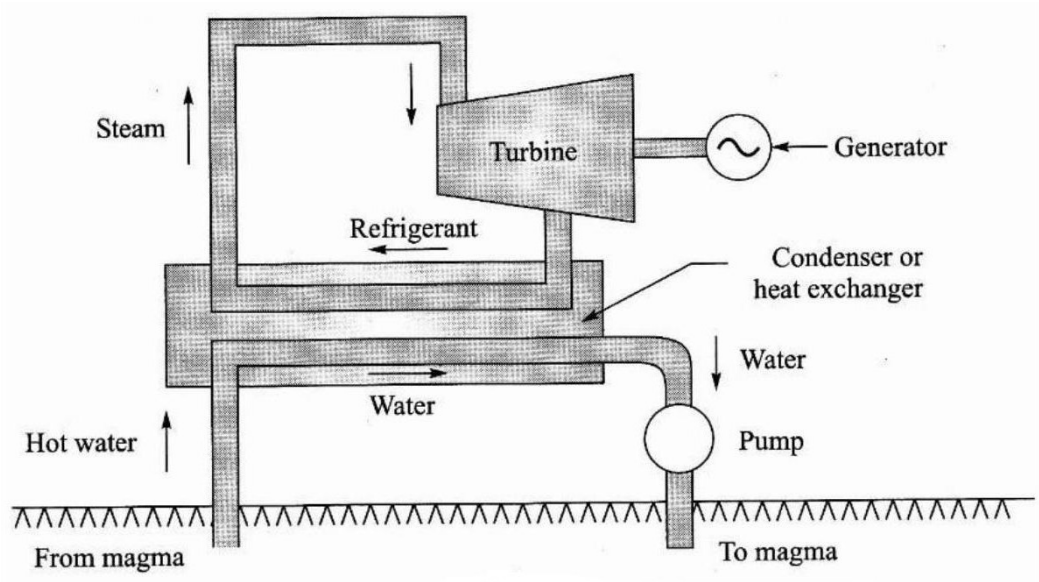
1.4.8. <u>Geothermal energy</u>:

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 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.



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. **<u>Oil Shale and Tar Sands</u>:**

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

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

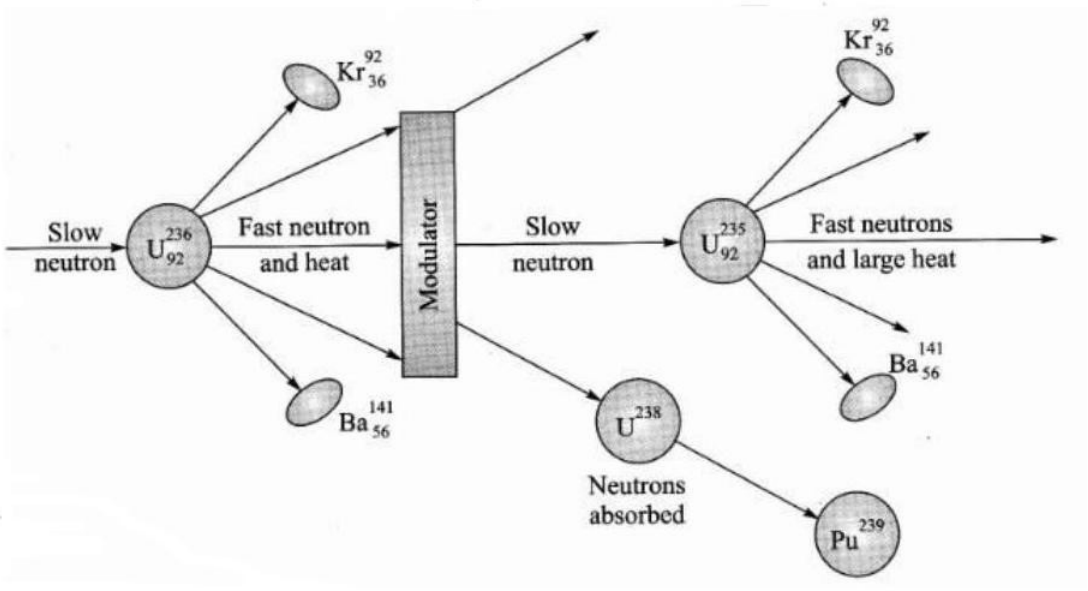
- Costs of fuel production from oil shale have not yet been fully evaluated.
- Disposal of the used shale could create ecological problems. Some studies have revealed soil and groundwater contamination to various degrees by chemicals or pollutants from the oil shale tailings.

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:

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



Fission process in the nuclear cell

5. Energy Parameters

The consumption of energy as well as the growth of energy requirement has to be monitored by every nation. To conserve energy resources, it is necessary for every nation to adopt measures to maximize economic development with minimum energy consumption. The energy parameters are measured using the yardstick of gross domestic product (GDP). The GDP is the value of all finished goods and services produced in a given period.

1. Energy Elasticity:

It is defined as the growth in energy requirement per GDP

$$\textit{Energy elasticity} = \frac{growt\ h\ in\ energy\ \ requirement}{GDP}$$

The energy should contribute in increasing the GDP. The lower is the value of energy elasticity the more is the growth of GDP. The value of energy elasticity for the developed countries ranges from 0.8 to 1.0. The value of energy elasticity for India is about 1.2. Hence, in our country, there is scope for

improvement in the efficiency of energy consumption as well as energy saving in industry.

1.5.2 Energy Intensity:

The energy intensity is defined as the ratio of energy consumption and GDP

$$\textit{Energy intensity} = \frac{energy\ \ consumption}{GDP}$$

The energy ratio is a measure of the efficiency in utilizing energy in developing national economy. High value of energy intensity indicates that higher amounts of energy resources are used in converting these resources to national GDP or economy. Lower energy intensity indicates that a lower price or cost is made in converting energy resources into national GDP. Factors affecting energy intensity are as follows:

- Energy efficiency of the appliances and buildings by proper design and provision of insulation.
- Fuel economy of vehicles.
- Frequency of travel and larger geographical distances, resulting in greater travelling and energy consumption.
- Economical means and pattern of transportation.
- Availability of mass transit system and its capacity and utilization. Efforts to conserve energy.
- Weather with mild temperature not requiring heating or cooling.

3. Energy policy in India:

The Government of India has formulated an energy policy to ensure adequate energy supply at minimum cost, self-sufficiency in energy supplies and protection of environment from an adverse impact of utilizing energy resources in any unjust manner. The policy has the following features:

- Accelerated exploitation of domestic conventional energy resources such as fossil fuels, hydro and nuclear energy.
- Intensification of exploration to achieve, indigenous production of oils and gases.
- Management of demand of oil and other forms of energy.
  Energy conservation and its management.
- Optimum utilization of existing capacity in the country.
- Development and exploitation of renewable source of energy to meet energy requirement of rural communities.
- Intensification of resources and development activities in new and renewable energy resources.

- Organization of training for personal engaged at various levels in the energy sector.

6. Environmental aspects of energy

1. Pollution:

What are the pollutants produced during energy conversion? What do you understand by indoor and outdoor pollution? What are the remedial actions?

During every energy conversion process, some energy is released into the atmosphere in the form of heat. Some pollutants in the form of gases are also produced during conversion and these gases are also emitted into the surroundings. Both heat and gases can cause degradation of the environment. The emitted gases are as follows:

- Carbon dioxide ($C0_2$), Excess emission of CO_2 in the atmosphere causes global warming.
- Carbon monoxide (CO). It severely impairs the oxygen-dependent tissues in the human body.
- Sulphur oxide (SO).It causes respiratory diseases, acid rains and corrosion of metals and building stones.
- Nitrogen oxide (NO). It can cause respiratory and cardiovascular diseases, deprive body tissues of oxygen and form acid in lungs.

<u>pollution can be of following types:</u>

- *Indoor pollution*. Indoor pollution occurs by the use of conventional chullahs in rural areas. Nearly 5 lakh children and women die every year from diseases caused by indoor air pollution. Indoor pollution can be avoided by the use of improved house hold stove.

- *Outdoor pollution*. This is mainly caused by the use of fossil fuels (coal and oil) in industry and transports.

<u>The remedial actions are as follows</u>

- Lesser use of fossil fuels and use of more gasified coal.
- Alternative fuels such as hydrogen which are non-polluting should be used.
- Vehicles running on electricity or battery to be used instead of IC engines.

1.6.2 Greenhouse Effects:

A greenhouse made of transparent glass sheets behaves differently to incoming shortwave radiation and outgoing long wave radiation. It allows the entry of sunlight but prevents the exit of heat (reflected infrared radiation). The greenhouse can maintain a controlled and warm environment inside for growth of plants. The earth has an envelope of carbon dioxide ($C0_2$) which behaves similar to greenhouse. The envelope allows heat from sun to enter but prevent heat to escape from earth by stopping reflected infrared radiation. This phenomenon of greenhouse effect by CO_2 envelope helps' the earth to maintain the surface temperature to 15°C (hospitable to life), otherwise the earth would become a frozen planet. Normal concentration of CO_2 is about 0.03% and any increase in the concentration of CO_2 will upset the temperature balance, resulting in further warming of the globe. The carbon dioxide emission is more from developed countries, accounting for 82% of total greenhouse gas emission of the world.

1.7 Energy Chain

The primary energy sources in the raw form cannot be used directly. It is impossible to drive a vehicle or electric motor using coal, petroleum or uranium. The energy available in primary energy sources is called raw energy. The primary energy sources have to be transformed into useful forms of energy resources which are then called secondary energy resources fuels.

The sequence of energy transmission from primary to secondary energy is called energy chain or energy route as shown in Figure 1.8. Mechanical energy, electrical energy and thermal energy can be obtained from primary and secondary energy resources.

Primary energy source	Processing	Secondary energy resources or fuels	Transmission	Consumer

Part A

Unit – II:

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.*

Solar Radiation Geometry: *Flux on a plane surface, latitude, declination angle, surface azimuth angle, hour angle, zenith angle, and solar altitude angle, expression for angle between the incident beam and the normal to a plane surface (No derivation) local apparent time. Apparent motion of sun, day length, numerical examples.*

Solar Energy – General Aspects:

Sun and Earth Sun

- It is a sphere of very hot gases and its largest members of the solar system.
- The diameter of the sun is 1.39×10^6 km
- The distance between the sun and earth is 1.496×10^8 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.

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

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, $E = s\sigma T^4$

Where s = Emissivity of the surface, σ = Stefan's Boltzmann constant and T_c = 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°.

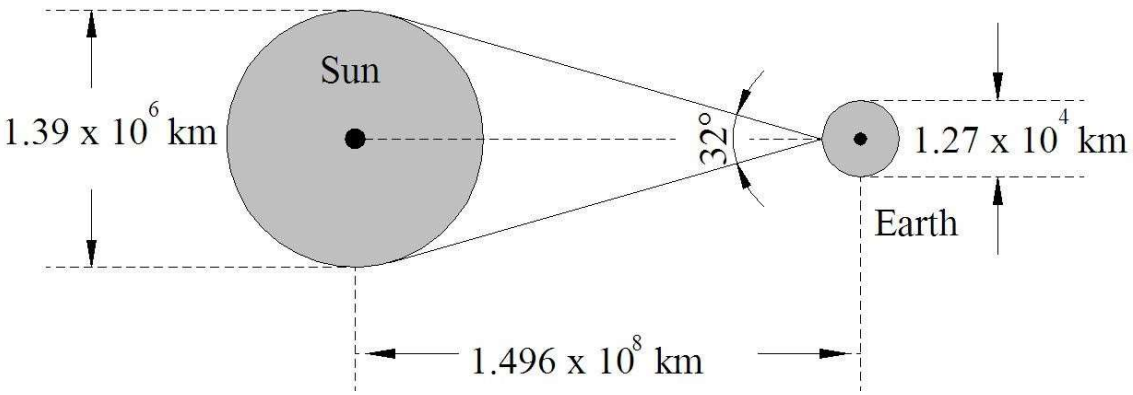


Figure 2.1 Sun and Earth in the solar system.

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).

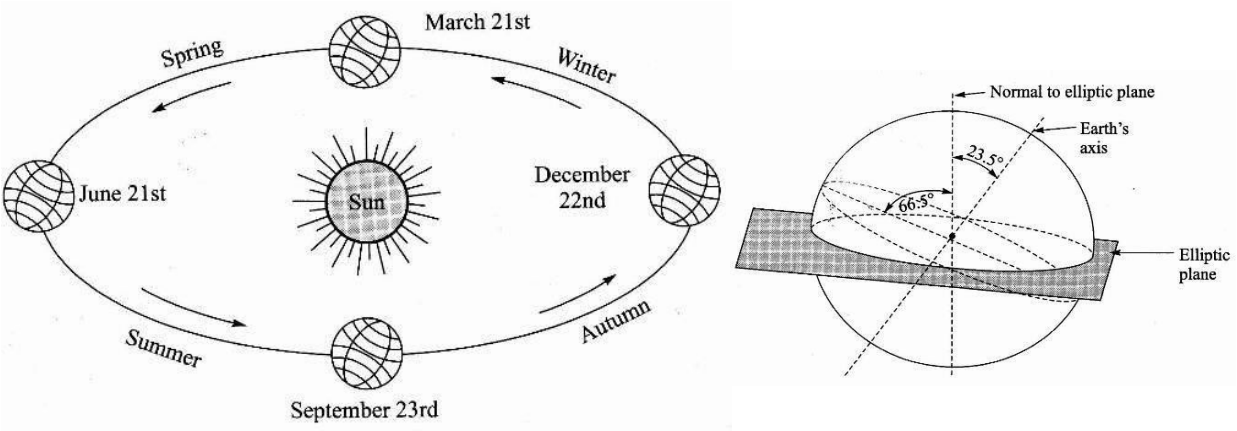


Figure 2.2 (a) Elliptical orbit of Earth's revaluation (b) Inclination of Earth's axis

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.

Solar Radiation:

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.

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]

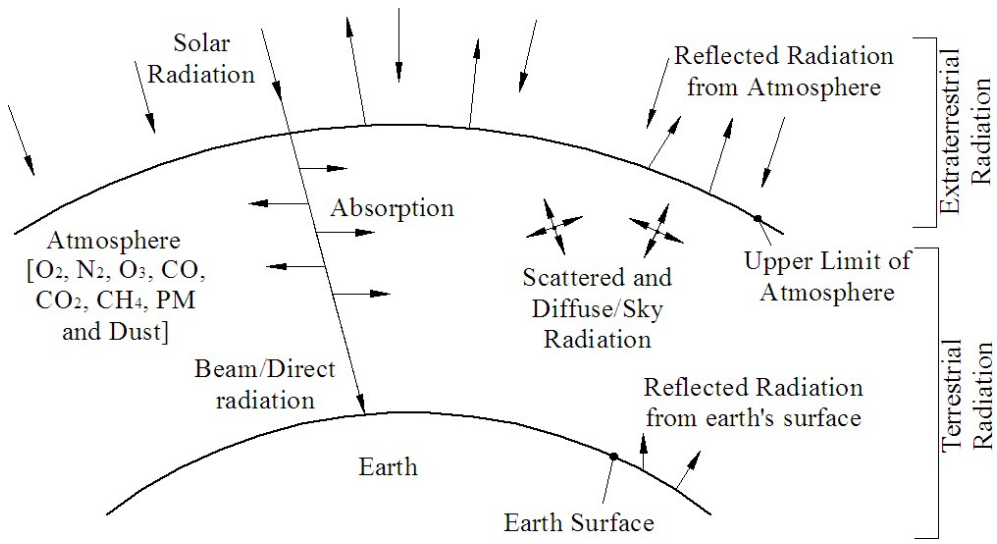


Figure 2.3 Solar Radiation

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

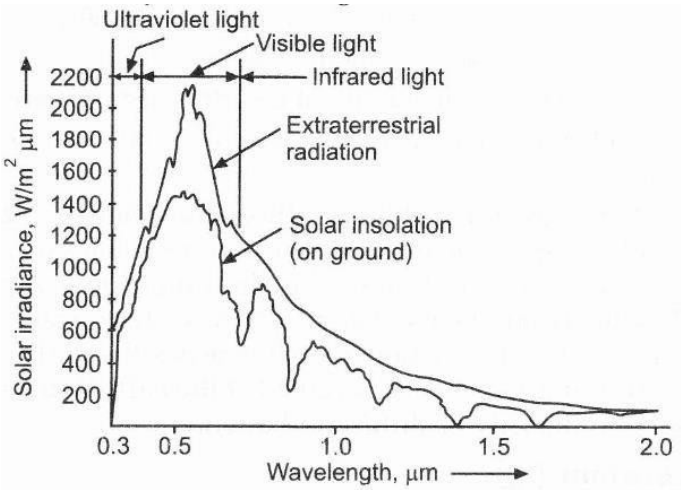


Figure 2.4 Spectral Distribution of Extraterrestrial Solar Radiation

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.

"*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.

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

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.

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*'.

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. As shown in Figure 2.5

Mathematicaly $Air\ mass(m)=\frac{path\ lenght\ travelled\ by\ beam\ radiation}{vertical\ path\ length\ of\ the\ atmosphere}=\frac{AC}{AB}$

$$\therefore Air\ mass(m)=cosec\ \alpha\ or\ sec\ \theta_z$$

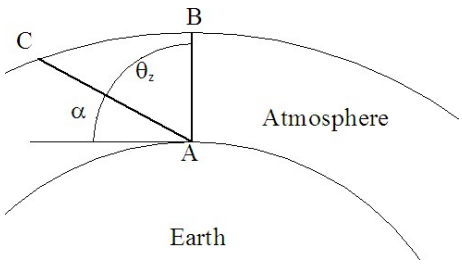


Figure 2.5 Concept of Air mass

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%)

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.

***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 ($\lambda < 0.38\ \mu m$).
  (c) Water vapor (H_2O) and carbon dioxide absorb almost completely the infrared radiation in the range ($\lambda > 2.3\ \mu m$) 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.

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- h/m^2-day of kJ/m^2-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(I_g and I_d), the amount received per day ($\bar{H}_g$ and $\bar{H}_d$) and sunshine hours per day ($\bar{S}$) 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.

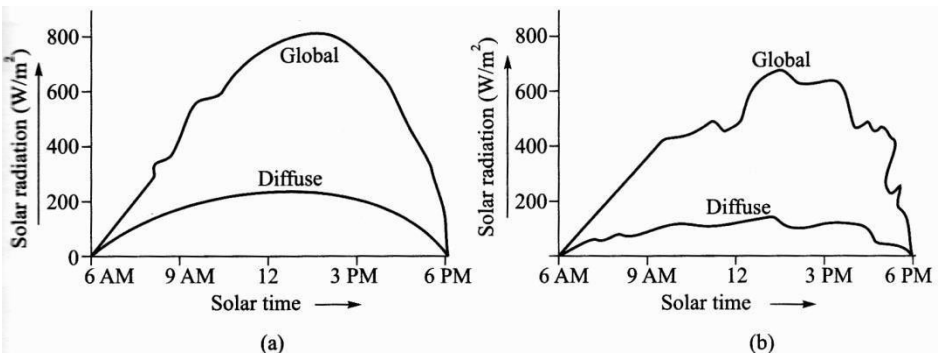


Figure 2.6 Daily Variation of Global and Diffuse radiation data measured on a horizontal surface (a) Clear sky (b) cloudy sky

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

	$\bar{I}_g$														$\bar{H}_g$	$\bar{S}$
	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 $\bar{I}_g$, daily global radiation $\bar{H}_g$ and sunshine hours $\bar{S}$

N.B. Time indicated is LAT. Value of I_g 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)

	$\bar{I}_d$														$\bar{H}_d$
	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 $\bar{I}_d$, daily global radiation $\bar{H}_d$

N.B. Time indicated is LAT. Value of I_g 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)

	$\bar{I}_g$														$\bar{H}_g$	$\bar{S}$
	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 $\bar{I}_g$, daily global radiation $\bar{H}_g$ and sunshine hours $\bar{S}$

N.B. Time indicated is LAT. Value of I_g 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/m ²-h)

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

	$\bar{I}_d$														$\bar{H}_d$
	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 $\bar{I}_d$, daily global radiation $\bar{H}_d$

N.B. Time indicated is LAT. Value of I_g 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/m ²-h)

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.

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.

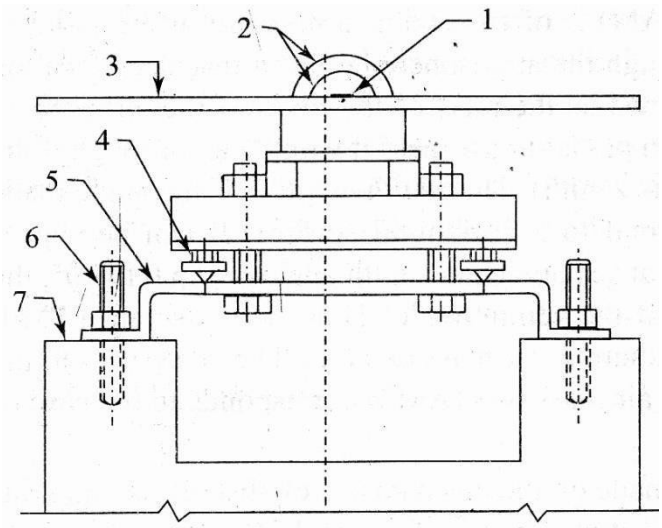


Figure 2.7 Pyranometer for measuring global Radiation

(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.

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.

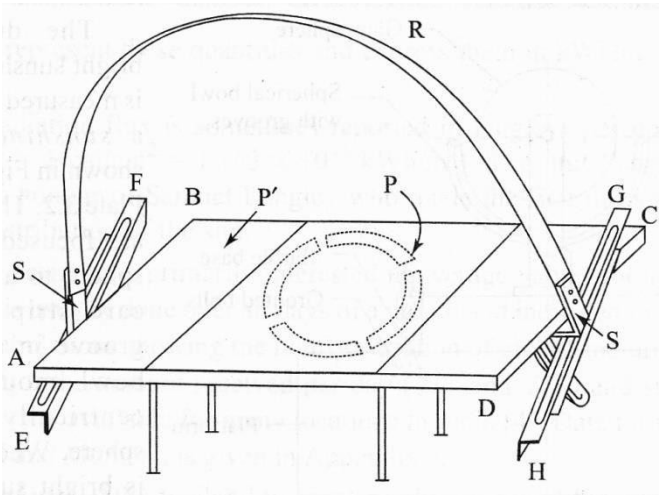


Figure 2.8 shading ring for measurement of diffuse radiation

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.

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.

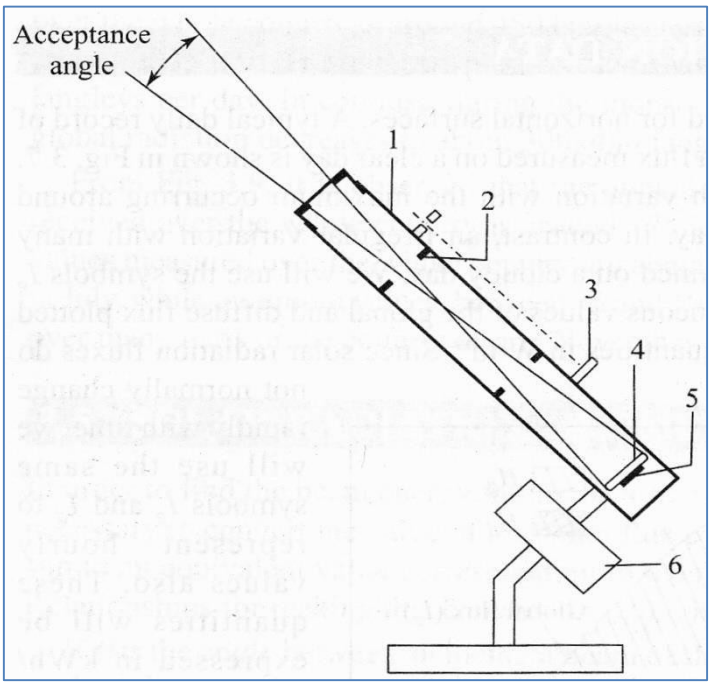


Figure 2.9 Pyrheliometer for measuring beam radiation

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

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

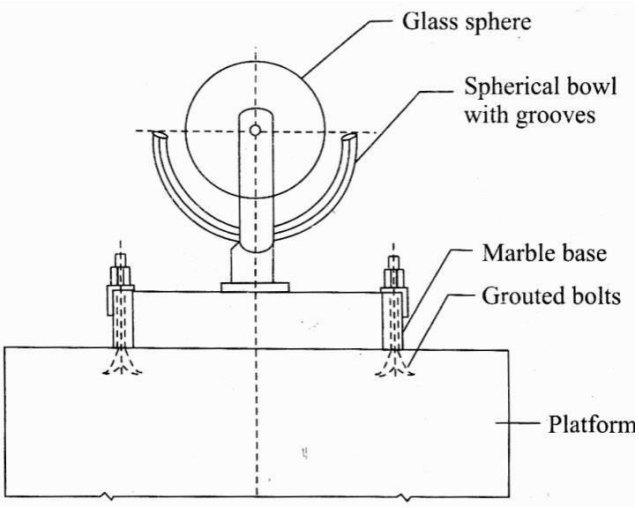


Figure 2.10 Sunshine recorder

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

Solar Radiation Geometry

Latitude (Angle of Latitude), (Ø): The latitude of a location on the earth's surface is the angle made by the radial line joining the specified location to the centre of the earth with the projection of this line on the equatorial plane as shown in the Figure 2.11. The latitude is positive for northern hemisphere and negative for southern hemisphere.

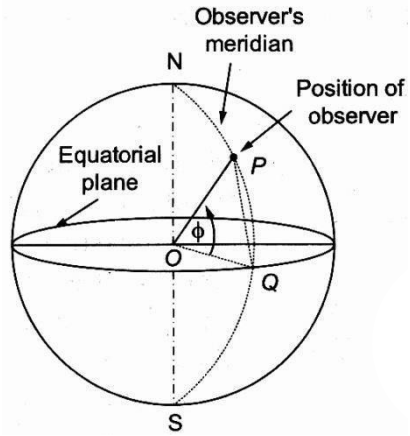


Figure 2.11 Latitude

Declination angle, (δ): It is the angle made by the line joining the centers of the sun and earth with the equatorial plane as shown in Figure 2.12. The angle of declination varies when earth revolves around the sun. It has a maximum value of 23.45° when the earth achieves a position in its orbit corresponding to 21st June and has a minimum value of -23.45° when the earth is in orbital position corresponding to 21st December. The angle of declination is taken positive when it is measured above the equatorial plane in the northern hemisphere. The angle of declination is given by the equation

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

Where '*n*' is the number of days from January 1.

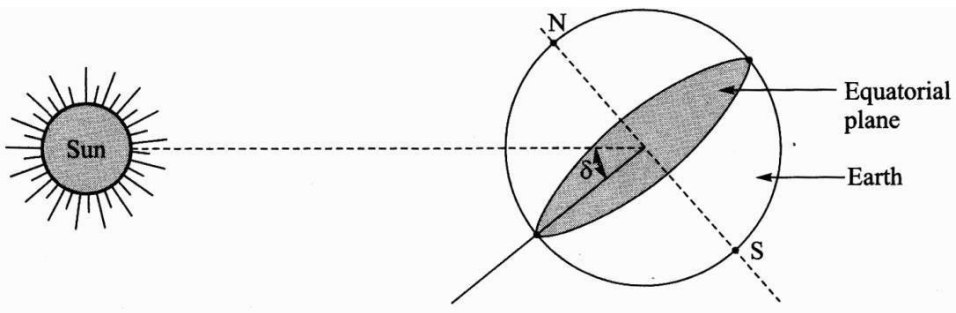


Figure 2.12 Declination angle

Hour angle, (ω): The hour angle at any instant is the angle through which the earth has to turn to bring the meridian of the observer directly in line with sun ray's. It is an angular measure of time. It is the angle in degree traced by the sun in one hour with reference to the twelve noon of the location. The convection of measuring it is that noon-based calculated local apparent time (LAT) is positive in afternoon and negative in forenoon as shown in Figure 2.13. The earth completes one rotation (360°) in 24 hours. Hence one hour corresponds to 15° of earth's rotation. As at solar noon the sun rays in line with local meridian or longitude, the hour angle at that instant is zero. The hour angle is given by the equation

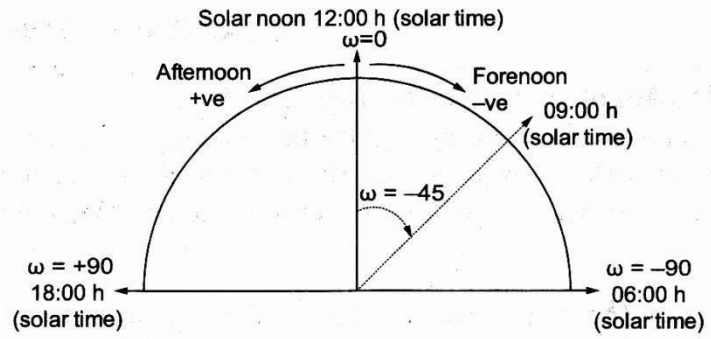


Figure 2.13 Hour angle

$$\omega = [\text{Solar time-12}] * 15°$$

Inclination or Altitude angle, (α): The angle between the sun's ray and its projection on a horizontal surface is known as the inclination angle, as shown in the Figure 2.14

Zenith angle, (θ_z): It is an angle between sun's ray and the perpendicular to the horizontal plane as shown in Figure 2.14

Solar Azimuth angle, (γ_s): It is the angle on a horizontal plane, between the line due south and the projection of the sun's ray on the horizontal plane. It is taken as positive when measured from south towards west.

Surface Azimuth angle, (γ): It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal to the inclined plane surface (flat plate collector) as shown in Figure 2.14. It is taken as positive when measured from south towards west.

Slope or Tilt angle, (β): It is the angle between the inclined plane surface (flat plate collector) and the horizontal plane as shown in Figure 2.14. It is taken to be positive for the surface sloping towards south.

Angle of incidence, (θ): The angle of incidence for any surface is defined as the angle formed between the direction of the sun ray and the line normal to the surface as shown in Figure 2.14.

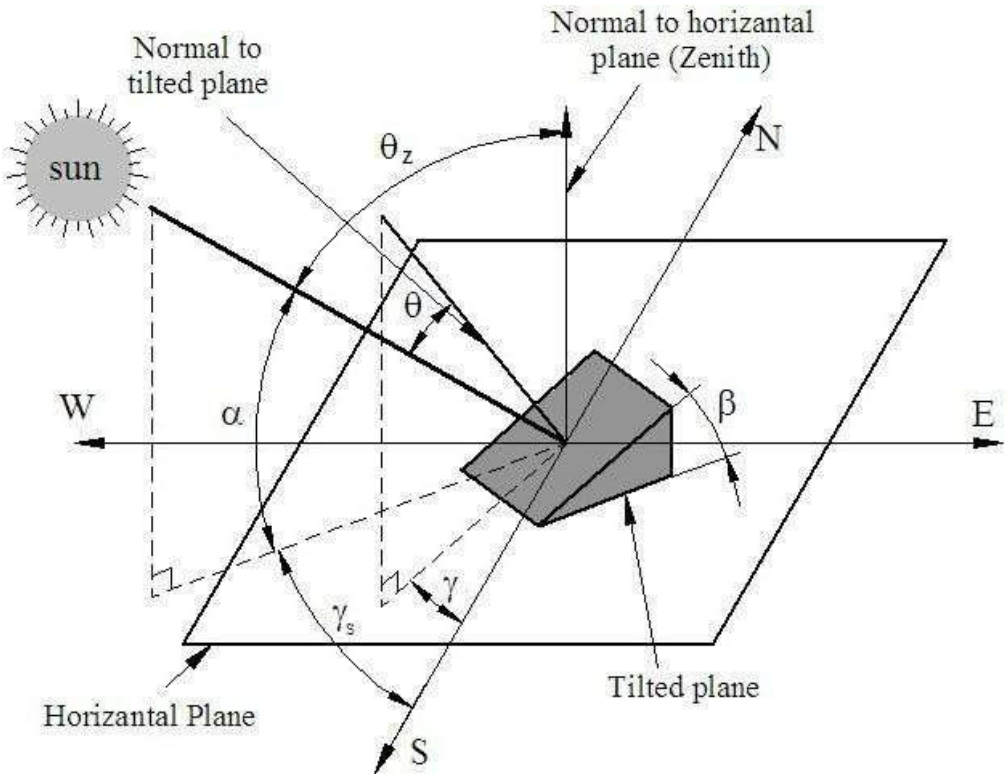


Figure 2.14 Solar radiation geometry

General equation for cos θ

$$\cos\theta = [\sin Ø\ (\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta) + \cos Ø\ (\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma\sin\omega\sin\beta]$$

Where,

θ	:	Angle of incidence
Ø	:	Angle of latitude
δ	:	Angle of declination
γ	:	Surface azimuth angle
β	:	Tilt angle

1. *For a vertical surface: $\beta = 90°$:*

$$\cos\theta = \sin\emptyset \cos\delta \cos\gamma \cos\omega - \cos\emptyset \sin\delta \cos\gamma + \cos\delta \sin\gamma \sin\omega$$

Note: ($\sin 90° = 1$, $\cos 90° = 0$)

2. *For a horizontal surface: $\beta = 0°$: $\theta = \theta_z$ (Zenith angle)*

$$\cos\theta = \cos\theta_z = \sin\emptyset \sin\delta + \cos\emptyset \cos\delta \cos\omega$$

Note: ($\sin 0° = 0$, $\cos 0° = 1$)

Also,

$$\cos\theta = \cos\theta_z = \sin\alpha \left(\text{since } \theta_z = \frac{\pi}{2} - \alpha\right)$$

3. *Surface facing south: $\gamma = 0°$:*

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

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

4. *Vertical surface facing south: $\beta = 90°$, $\gamma = 0°$:*

$$\cos\theta = \sin\emptyset \cos\delta \cos\omega - \cos\emptyset \sin\delta$$

The angle of incidence can also be expressed in terms of θ_z *(Zenith angle)* as:

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

$$\cos\gamma_s = \left(\frac{\cos\theta_z \sin\emptyset - \sin\delta}{\sin\theta_z - \cos\emptyset}\right)$$

Latitude and longitude

Latitude: On a globe of the earth, line of latitude is circle of different sizes. The largest one is at the circle of equator (circle at equator with centre at earth's centre) whose latitude is taken as zero. The circles at the poles have latitude of 90° North and 90° South (or -90°) where these circles shrink to a point, there are 180 circles of which 90 in each hemisphere specify the latitude of various points on earth's surface as shown in Figure 2.15 (a). Each degree of latitude is about 111 km apart. Latitude lines run horizontally and these lines are parallel.

Longitude: On the globe, vertical lines of constant longitude (meridians) extend from pole to pole similar to the segment boundaries on a peeled orange. Every meridian has to cross the equator and equator is a circle, like any circle, it has 360° of divisions. Hence, the longitude of a point is marked a value of that division where its meridian meets the equator circle. The meridian passing through the Royal Astronomical observatory at Greenwich, UK has been chosen as zero latitude. The meridian passing through this location is called prime meridian. This prime meridian or longitude is considered zero longitude and there are 180 longitude lines or degree as cast (+180°) and 180° at west (-180°) of Greenwich. The longitude lines meet at poles and these have wide separation at equator about (111 km). The longitudinal lines are shown in Figure 2.15 (b). Solar noon is the time when the sun is at the longitude of place.

Apparent motion of the sun

To an observer on the earth, on any given day, the sun rises in the east, moves in a tilted plane in the angle of [90° - Ø] with the horizontal, and finally sets in the west. Thus, the apparent plane in which the sun moves intersects the horizontal plane in a line positioning east-west. However because of the declination angle this E-W line of intersection does not coincide with E-W passing through the observer O. for a location in the northern hemisphere, this line is to the south in winter (declination negative, 21st December with an angle of -23.45°) to the north in summer (declination positive, 21st June with an

angle of 23.45°) and coincides with the E–W line passing through the observer on two equinox days i.e. 21st March & 21 September (declination iszero).

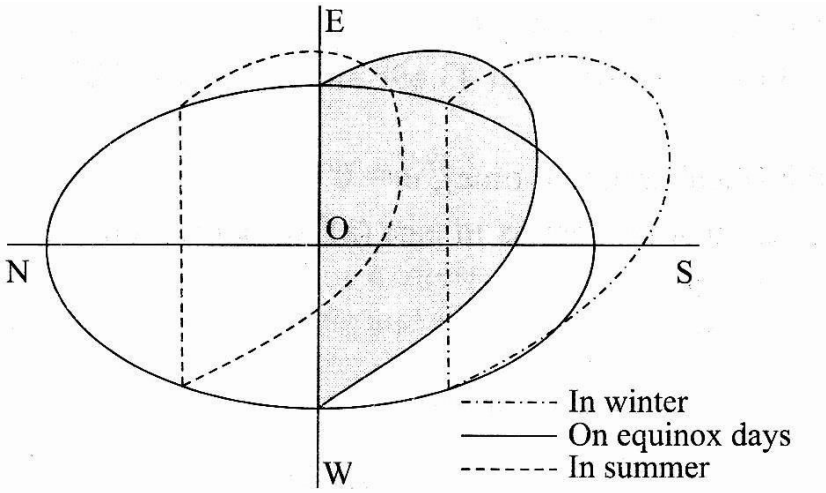


Figure 2.15 Apparent motion of the sun

Local Apparent Time (LAT)

The time used for calculating the hour angle ω is the local apparent time. This can be obtained from the standard time observed on a clock by applying two corrections. The first correction arises because of the difference between the longitude of a location and the meridian on which the standard time is based. The correction has magnitude of 4 minutes for every degree difference in longitude. The second correction called the equation of time correction due to fact that earth's orbit and rate of rotation are subjected to small variations. This correction is based in experimental observations and is plotted in Figure 2.15.

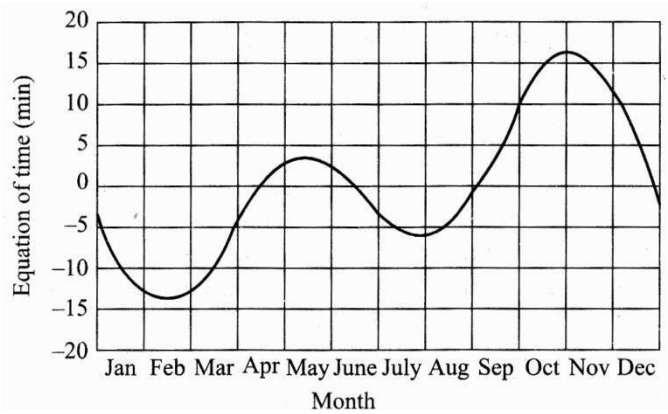


Figure 2.16 Equation of time correction

Thus, LAT = standard time ± 4 (standard time longitude – longitude of location) + (equation of time correction)

The equation of time correction (in minutes) can also be calculated from following empirical relation

$E = 229.18\ (0.000075 + 0.001868 \cos B - 0.032077 \sin B - 0.014165 \cos 2B - 0.04089 \sin 2B)$

Sunrise, sunset & Day length

Horizontal surface: The hour angle corresponding to sunrise or sunset (ω_s) on a horizontal surface is given by

$$\cos \omega_s = -\tan \text{Ø} \tan \delta, \therefore \omega_s = \cos^{-1}(-\tan \text{Ø} \tan \delta) \quad \text{in degree}$$

If an above equation yields a positive value then it is sunrise, if it yields negative value then it is sunset, then corresponding day length is given by the equation

$$L_d = \frac{2}{15}\omega_s = \cos^{-1}(-\tan \text{Ø} \tan \delta) \quad \text{in hours}$$

Inclined surface facing due south:

$$\omega_{st} = \cos^{-1}(-\tan(\emptyset - \beta)\tan\delta)$$

$$|\omega_{st}| = \min[|\cos^{-1}(-\tan\emptyset\tan\delta)|, |\cos^{-1}(-\tan(\emptyset - \beta)\tan\delta|]$$

Inclined surface facing due north:

$$\omega_{st} = \cos^{-1}(-\tan(\emptyset + \beta)\tan\delta)$$

$$|\omega_{st}| = \min[|\cos^{-1}(-\tan\emptyset\tan\delta)|, |\cos^{-1}(-\tan(\emptyset + \beta)\tan\delta|]$$

Estimation of average solar radiation

Angstrom's equation for average global radiation:

The expression for the average radiation on a horizontal surface in terms of constants *a* and *b* and observed values of average length of solar days, as suggested by angstrom is given by

$$\frac{H_g}{H_c} = a + b\left(\frac{L_a}{L_m}\right)$$

Where H_g = Monthly average of daily global radiation on a horizontal surface at the location in (kJ/m^2 day)

H_c = Monthly average of the daily global radiation on the same horizontal surface at the same location but on clear sky day (kJ/m^2 day)

a, b = Constants determined from various cities in the world by measurements

L_a = Average length of solar day for a particular month calculated or observed (in hours)

L_m = Length of the longest solar day in the month (in hours)

Modified Angstrom's equation

The modified Angstrom's equation is written by replacing H_c by H_o in the above equation.

$$\frac{H_g}{H_o} = a + b\left(\frac{L_a}{L_m}\right)$$

Where H_o = Monthly average of the daily extraterrestrial radiation, which would fall on a horizontal surface at the location under consideration (in kJ/m^2 day)

The expression for H_o is given by

$$H_o = I_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\int[(\sin\emptyset\sin\delta) + (\cos\emptyset\cos\delta\sin\omega)]dt$$

Where,

n = Number of days in the year
I_{sc} = *Solar Constant*
$\emptyset$ = Angle of latitude for location
δ = Angle of declination of equatorial plane
ω = hour angle for local apparent time

The integral $\int dt$ in above equation is in terms of hours. It can be changed to an angle of $\int d$ in radians.

Now,

$$1\ hour = 15^\circ = \frac{15\pi}{180} rad.$$

$$\therefore dt = \frac{180}{15\pi} d\omega = \frac{12}{\pi} d\omega$$

Inserting the value of dt in the H_o equation and integrating between sun rise ($-\omega_s$) to ($+\omega_s$) for a total day light period we get

$$H_o = \frac{12}{\pi} I_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365}\right)\right] \int_{-\omega_s}^{+\omega_s} (\sin \emptyset \ \sin \delta + \cos \emptyset \cos \delta \cos \omega) d\omega$$

By solving the integral we get

$$H_o = \frac{24}{\pi} I_{sc} \left[\left\{1 + 0.033 \cos\left(\frac{360n}{365}\right)\right\} (\omega_s \sin \emptyset \sin \delta + \cos \emptyset \cos \delta \sin \omega_s)\right] \text{kJ/m}^2 \text{ day}$$

The value of H_o can be calculated for a clear sky day on a flat surface location.

Hence the value of H_g (daily global radiation-monthly average) for a horizontal surface at the location is then calculated by using the values of H_o, a, b in the modified Angstrom's equation

H_o can be obtained from charts or can be calculated by following empirical relation

$$H_o = \frac{24}{\pi} I_{sc} \left[\left\{ 1 + 0.033 cos \left(\frac{360}{365} n \right) \right\} \left(\cos \emptyset \cos \delta \cos \omega_s + \frac{2\pi\omega_s}{360} \sin \emptyset \sin \delta \right) \right]$$

Sl No	*City*	*a*	*b*	*Mean percentage error*
01	Ahmedabad	0.28	0.48	3.0
02	Bangalore	0.18	0.64	3.9
03	Bhavangar	0.28	0.47	2.8
04	Chennai	0.30	0.44	3.5
05	Goa	0.30	0.48	2.1
06	Jodhpur	0.33	0.46	2.0
07	Kodaikanal	0.32	0.55	2.9
08	Kolkata	0.28	0.42	1.3
09	Mangalore	0.27	0.43	4.2
10	Minicoy	0.26	0.39	1.4
11	Nagpur	0.27	0.50	1.6
12	New Delhi	0.25	0.57	3.0
13	Pune	0.31	0.43	1.9
14	Shilong	0.22	0.57	3.0
15	Srinagar	0.35	0.40	4.7
16	Thiruvananthapuraam	0.37	0.39	2.5
17	Vishakhapatanam	0.28	0.47	1.2

Table 2.5 constants for a and b for Indian cities

Example 2.1: Determine the sunset hour angle and day length at allocation of latitude of 32° on March 30.

Given data, *Ø = 32°, day of the year = March 30*.

Solution,

The total number of days up to March 30 is i.e. n = 31 + 28 + 30 = 89
Jan Feb Mar

The declination angle is given by the equation,

$$\delta = 23.45 \sin \left[\frac{360}{365} (284+n) \right] = 23.45 \sin \left[\frac{360}{365} (284+89) \right] = \mathbf{3.22°}$$

Hour angle is calculated by the equation,

$$\omega_s = \cos^{-1}(-\tan \emptyset \tan \delta) = \cos^{-1}(-\tan 32° \tan 3.22°) = \mathbf{92.01°}$$

Day length is given by the equation,

$$L_d = \frac{2}{15}\omega_s = \frac{2}{15}92.01 = 12.268 \text{ hours} = \mathbf{12^h16'08''}$$

Example 2.2: Determine the day length in hours at New Delhi (latitude = 28.6°) on June 28 in a leap year.

Given data, *Ø = 28.6°, day of the leap year = June 28.*

Solution,

The total number of days up to June 28 is i.e.

n = 31 + 29 + 31 + 30 + 31 + 28 = 180 days

Jan Feb Mar Apr May Jun

The declination angle is given by the equation,

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+n)\right] = 23.45 \sin\left[\frac{360}{365}(284+180)\right] = \mathbf{23.24°}$$

Hour angle is calculated by the equation,

$$\omega_s = \cos^{-1}(-\tan \emptyset \tan \delta) = \cos^{-1}(-\tan 28.6° \tan 23.24°) = \mathbf{103.54°}$$

Day length is given by the equation,

$$L_d = \frac{2}{15}\omega_s = \frac{2}{15}10.54 = 13.8 \text{ hours} = \mathbf{12^h48'}$$

Example 2.3: Calculate the Local Apparent Time (LAT) and declination at a location latitude 24°20' N, longitude 77°21' E at 12:30 IST on July 24. Equation of time correction is (-1' 06")

Part A

Unit – III:

Radiation Flux on Tilted Surface: *Beam, diffuse and reflected radiation, expression for flux on a tilted surface (no derivations) numerical examples*

Solar Thermal Conversion: *Collection and storage, thermal collection devices, liquid flat plate collectors, solar air heaters concentrating collectors (cylindrical, parabolic, paraboloid) (Quantitative analysis); sensible heat storage, latent heat storage, application of solar energy water heating. Space heating and cooling, active and passive systems, power generation, and refrigeration. Distillation (qualitative analysis) solar pond, principle of working, operational problems.*

Introduction:

Solar energy is clean, abundantly affordable renewable energy. Solar energy can be used in two ways directly as thermal energy and indirectly using solar photovoltaic cells to convert it to electricity. In cold climate region or other regions in winter, a large amount of thermal energy is required to heat air to maintain comfort conditions in space and to heat water for washing, cleaning and drying, both for domestic and industrial needs. Solar energy collectors are the devices similar to heat converter which are used to obtain thermal energy from solar energy. Solar energy is available during day time from sunrise to sunset. Solar energy of 5 to 7 kWh/m^2 is commonly available in most places in India. The solar energy can be used either in solar power plant or in a solar photovoltaic (SPV) cells to get electricity. Indian renewable energy development agency and they ministry of non-conventional energy sources are working continuously to install a solar energy in more than million house in shortest time and to increase the uses of solar energy for

- Domestic lighting
- Solar water heating
- Street lighting
- Village electrification
- Railway signals

- Desalination of saline water
- Water pumping
- Space heating
- Solar cooking
- Space cooling
- Solar greenhouse
- Power for remote telecommunication stations.

Solar collectors:

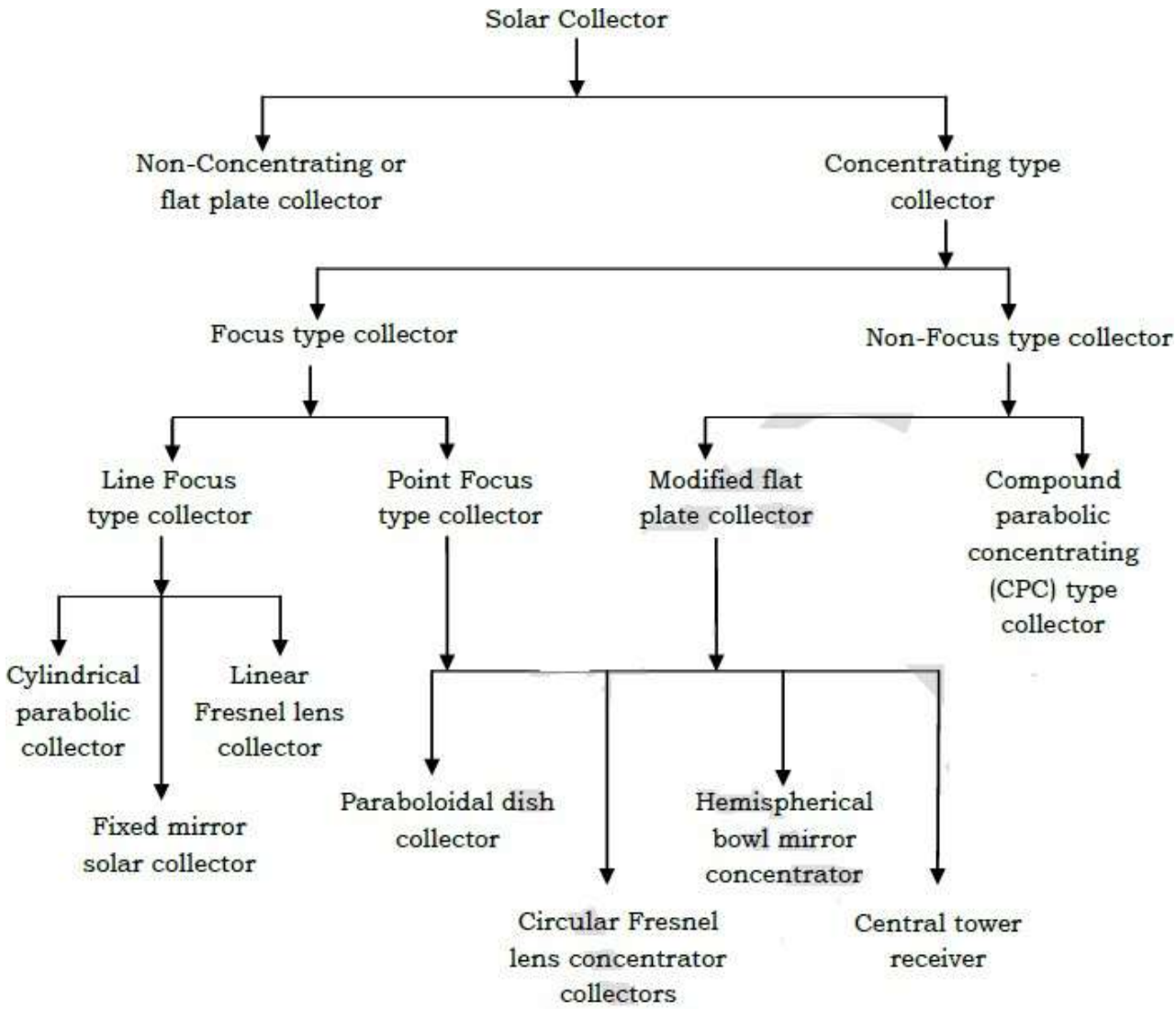
- What is the need for a solar collector?
- Write a short note on solar collector.

Solar energy reaching earth's surface has small intensity of about 5 to 7 kWh/m^2. Hence for any worthwhile application, sufficient solar energy should be collected from a large ground area with the help of many solar collectors. Solar collector is a device for collecting solar radiation and then transferring the absorbed energy to a fluid passing through it. A solar collector absorbs solar energy is in the form of heat and simultaneously transfers this heat to a fluid so that the heat can be transported by the fluid. The transport fluid takes this transferred heat from the collector and delivers it to a thermal storage tank, boiler or heat exchanger so that it can be utilized in a solar thermal system. Hence, solar collector is essential and it forms the first basic unit in a solar thermal system.

classification of solar collectors

- How are solar collectors classified? What are the important features of solar collector?
- Explain (a) collector efficiency (ii) concentration ratio and (iii) temperature range.
- Enumerate different types of concentrating solar collectors.

A solar collector is a device (a) to collect and absorb solar radiation and (b) to transfer the absorbed heat energy to the fluid (generally air or water) in contact or passing through it. There are mainly two types of solar collector
(a) non concentrating or flat plate collector and (b) concentrating collector as shown below. The solar energy collector with its associated absorber is the
essential component of any solar collector for the conversion of solar radiation energy into more usable form of energy such as heat or electricity.


Solar Collector
Non-Concentrating or flat plate collector
Concentrating type collector
Focus type collector
Non-Focus type collector
Line Focus type collector
Point Focus type collector
Modified flat plate collector
Compound parabolic concentrating (CPC) type collector
Cylindrical parabolic collector
Linear Fresnel lens collector
Fixed mirror solar collector
Paraboloidal dish collector
Hemispherical bowl mirror concentrator
Circular Fresnel lens concentrator collectors
Central tower receiver

In the non-concentrating solar collectors, the collector's or radiation interceptor's area is the same as that of observer's area. On the contrary, the interceptor's area is much time more than that of observer's area in the concentrating type collectors. By increasing the concentration of radiation energy, much higher temperature can be obtained in the collector's fluid and transportation. Concentrating collectors can be used to generate steam of medium temperature and pressure. The concentrating collectors use different arrangements of mirrors and lenses to concentrate solar radiation for effective generation of steam in the boilers and other devices. The concentrating type solar collectors have better efficiency than that of flat plate type collectors. To improve their efficiency, the collectors should be movable by the tracking system so as to make the collectors always facing the sun when the sun moves through the sky. The line focus type collectors require one axis tracking while the point focus type collectors require two axes tracking. The line focus, point-focus and non-focus type collectors are as enumerated in the classification as shown in the chart above.

While non-focus type collectors utilize both beam and diffuse radiation, the focus type collectors utilize only beam radiation as diffuse radiation cannot be focused. Concentrating collectors can increase the power flux of sunlight by hundreds of times. This class of collectors is used for high temperature applications, such as steam generation. Concentrating collectors are best suited to such climates that have a high percentage of clear sky days as cloudy days have diffuse radiation which cannot be concentrated. The main types of concentrating collectors are (i) parabolic dish collectors, (ii) parabolic trough collectors, (iii) power tower and (iv) stationary concentrating collectors. A solar photovoltaic concentrating module uses optical elements such as Fresnel lenses to increase the sunlight incidenting on it. Concentrating collector has to face sun and it needs tracking device to follow with the movement of the sun. Concentrating collectors for home or small business solar heating appliances are usually made of parabolic trough type collectors that can concentrate the solar radiation on an absorber tube or receiver which contains any fluid for heat transfer.

The important features of a solar collector are as follow:

- *Collector efficiency*: It is defined as the ratio of energy actually absorbed by the collector to the energy incident on the collector. The absorbed energy by a collector is the solar energy which is transferred to the transport fluid as heat energy.

$$\eta = \frac{\text{Energy absorbed}}{\text{Solar incident energy}}$$

- *Concentrating ratio (CR)*: It is defined as the ratio of the area of aperture of the collector system to the area of the receiver. The aperture of the system is the projected area of collector facing or normal to the sun as shown in Figure 3.1. The radiation is incident on an aperture area A_0 which is then concentrating on a smaller area on receiver or absorber plate given by A_r. The concentration ratio is

$$CR = \frac{A_0}{A_r} \; and \; CR_{max} = \frac{1}{\sin\theta_{max}}$$

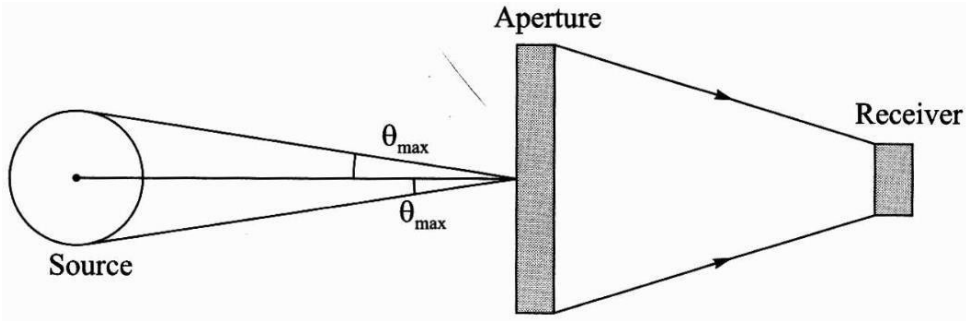


Figure 3.1 Concentrating ratio of solar collector

- *Temperature range*: It is the range of temperature to which the heat transporting fluid is heated up by the collector. The temperature range depends upon the concentration ratio. The flat plate collectors have concentration ratio of unity as no focussing or optical concentration system is utilized in them to concentrate the solar radiation. This is the reason why the temperature range of flat collectors is less than 100°C. Line focus collectors have concentration ratio up to 100 and these collectors can have temperature range on the order of 150-300°C. Point focus collectors have very high concentration ratio (CR > 1000) and these collectors have temperature range in the order of 500-1000°C.

Flat Plate Collector

- What is a flat plate solar collector?
- Explain the principle of conversion of solar energy to heat. Explain a flat plate solar collector.

Where temperatures below 70°C are adequate, as they are for space and service water heating flat plate collectors, which are of the non-concentrating type, are particularly convenient. They are made in rectangular panels, from about 1.7 to 2.9 m^2, in area, and are very simple in construction. These type of collectors absorb both beam and diffuse radiation.

The main parts of flat plate collectors are:

(i) Absorber plate: It is meant to intercept and absorb incident solar radiation. It is primarily a blackened heat absorbing plate usually made of copper, aluminum or steel. It may also be given a coating to minimize the emission of heat from its surface.

(ii) Transparent cover: It is made of one or more transparent sheets of glass or plastic. It is placed above the absorber plate. The cover allows radiation to

reach the absorber plate but it prevents any re-radiation and heat loss due to convection.

(i) *Fluid tubes or channels:* Fluid tubes or channels are arranged in thermal contact with the absorber plate so that heat can be transferred from the absorber plate to the fluid in the tubes or channels.

(ii) *Thermal insulation*: The thermal insulation is provided under the absorber plate and fluid tubes to minimize any heat loss by transmission or convection from the absorber plate and fluid tubes.

(iii) *Tight container or box*: All the above components of the collector are protected by a tight container or box as shown in Figure 3.3.

The characteristic of flat plate collectors are as fallows

(i) It absorbs both direct and diffuse radiation.
(ii) It doesn't need any sun tracking system. Hence, it is mathematically stronger than other collectors which require tracking system.
(iii) It has simple construction requiring a little maintenance.

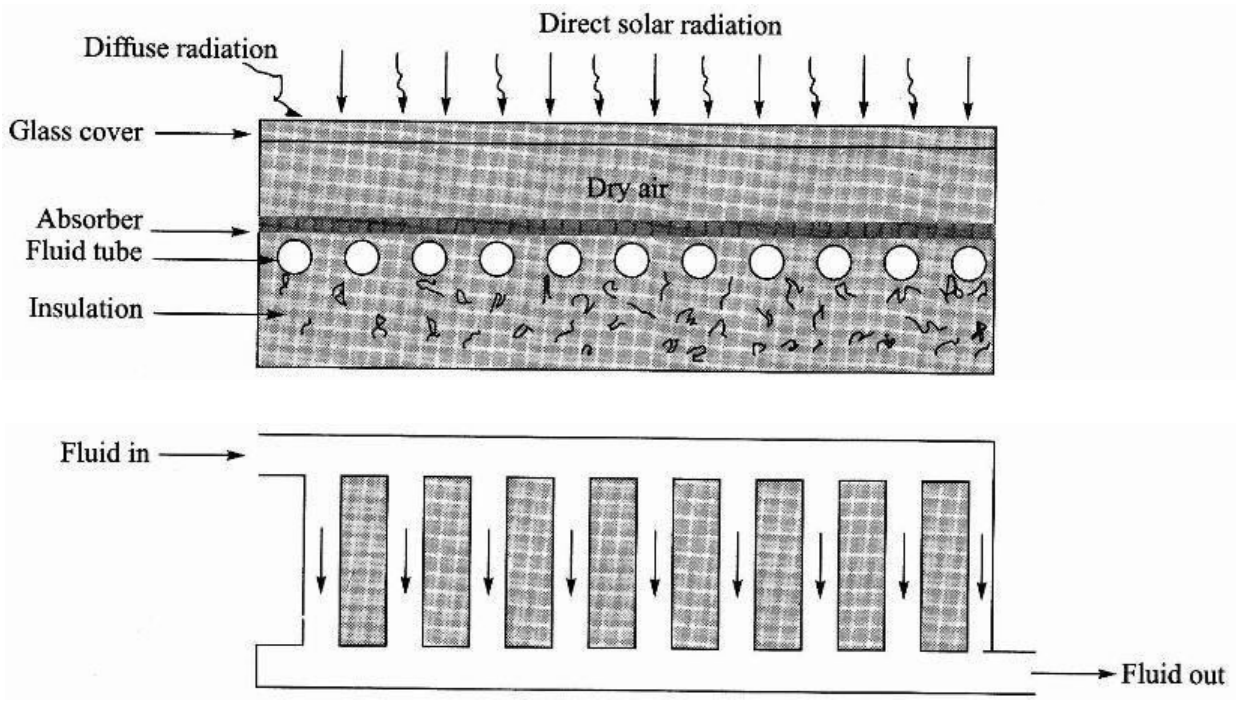


Figure 3. 2 schematic of flat plate collector

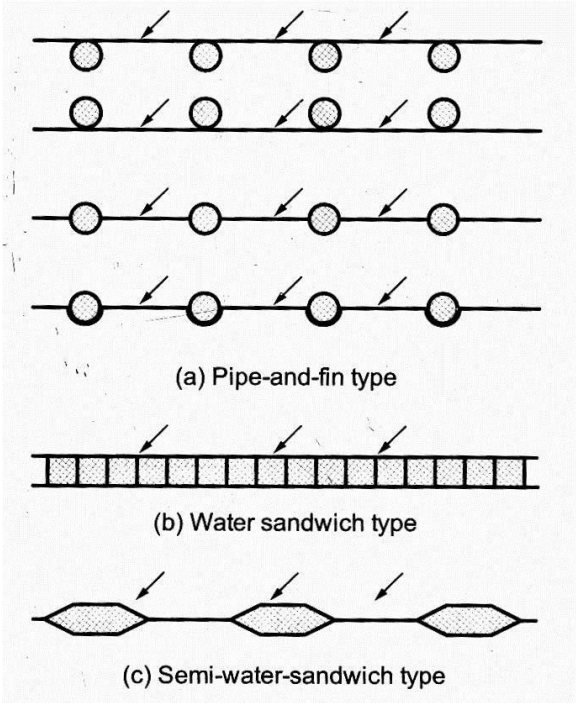


Figure 3.3 Cross section of absorber plate

The various cross sections of absorber plate are as fallows.

(a) Pipe-and-fin type, here the liquid flows only in the pipe and hence they have a comparatively low wetted area and liquid capacity

(b) Rectangular or Cylindrical sandwich, in this type both are wetted area and water capacity are high

(c) Roll-bond or semi-sandwich, in this type it as intermediate between the above two types.

Modified Flat Plate Collector

- Explain modified flat plate collector.

It is a modified form of the flat plate collector as it has plain reflectors at its edges to reflect additional radiation to the absorber or receiver and so there is some concentration of solar radiation at the receiver. The mirror reflectors are called booster mirrors which increase the acceptance angle and concentration ratio of the flat plate reflector from 1 to 4. The arrangement of the reflecting mirrors is shown in Figure 3.4

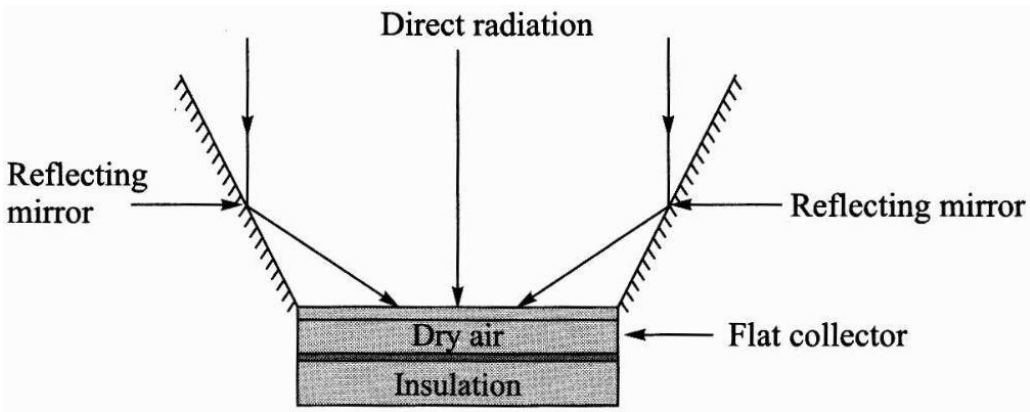


Figure 3.4 Modified Flat Plate Collector

Compound Parabolic Collector

- Write a short note on compound parabolic collector

The compound parabolic concentrator (CPC) is mainly a flat collector having two parabolic mirror reflectors attached at the edge of the flat plate collector as shown in Figure 3.5.

The parabolic mirrors are so adjusted that the focus of one mirror is located at the bottom end of the other mirror in contact with the receiver. The arrangement helps in increasing the acceptance angle. The concentration ratio achieved by this type of collectors ranges from 3 to 7.

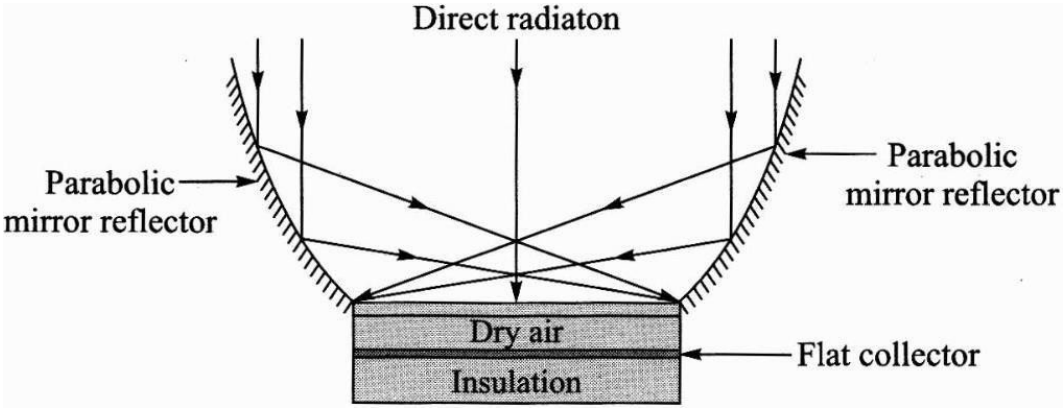


Figure 3.5 Compound Parabolic Concentrator

Cylindrical Parabolic Concentrator

- Describe a line focal concentrator
- Describe one axis tracking collector
- Describe briefly a cylindrical parabolic concentrator.

Cylindrical parabolic concentrator or parabolic trough collector consists of a cylindrical parabolic trough reflector with a metallic fluid tube or receiver tube containing fluid at its focal line as shown in Figure 3.6. In order to have better absorption of solar radiation, the fluid tube is blackened at outer surface. The concentrated solar radiation reaching the fluid tube heats up the transport fluid flowing through it. The collector with such concentrator has to be oriented to any of the following three directions: (i) East-West, (ii) North-South and (iii) Polar. Hence, such collector needs one-axis tracking system which can move the collector as per the sun's movements in sky. These types of collectors have the concentration ratio in the range of 5-30.

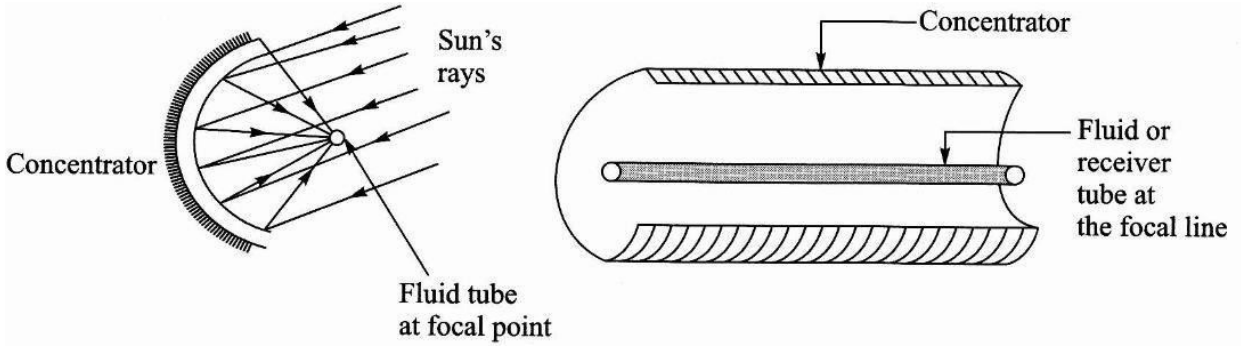


Figure 3.6 Cylindrical Parabolic Concentrator

Fixed Mirror Solar Concentrator

- Explain fixed mirror solar concentrator.
- Describe a collector having tracking receiver or fluid tube.

The concentrator consists of a number of long narrow mirror strips fixed on the circumference of a certain reference cylinder with a tracking receiver or fluid tube moving at the same circular circumference or focal circle as shown in Figure 3.7. The mirrors are arranged in such a manner that the incident radiation on them is focused on the receiver tube on their common focal circle. The receiver tube is made to move along the focal circle by a tracking device as per the movement of the sun in the sky. The concentration ratio of the concentrator is equal to the number of mirrors used for the concentration of radiation.

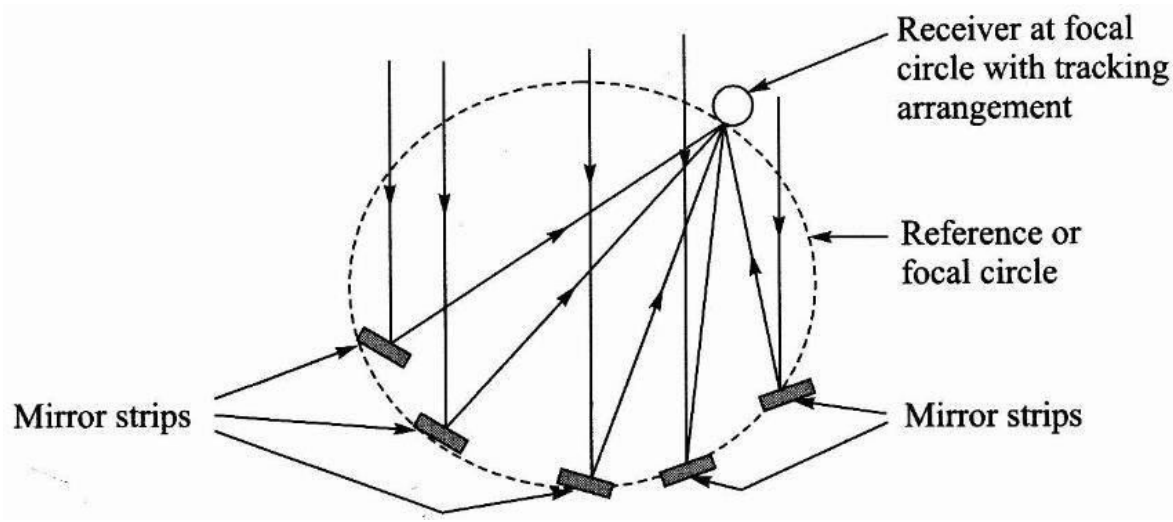


Figure 3.7 Fixed Mirror Solar Concentrator

Linear Fresnel Lens Collector

- Describe a mirror strip solar collector.
- Write short note on linear Fresnel collector.

In this type of collectors, a concentrator in the form of Fresnel lens is used. The Fresnel lens consists of fine and linear grooves formed on one of the surfaces of some refracting materials sheet while its other surface is flat. The grooves provided on the sheet are designed in such a manner that these behave similar to spherical lens to every incident light rays. The incident radiation, therefore, converges on the focal line of the lens system where fluid tube is provided as shown in Figure 3. 8. The heat is transferred to the transport fluid flowing in the fluid tube. A concentration ratio ranging from 10 to 30 is achieved. The temperature range of such collectors varies from 150°C to 300°C.

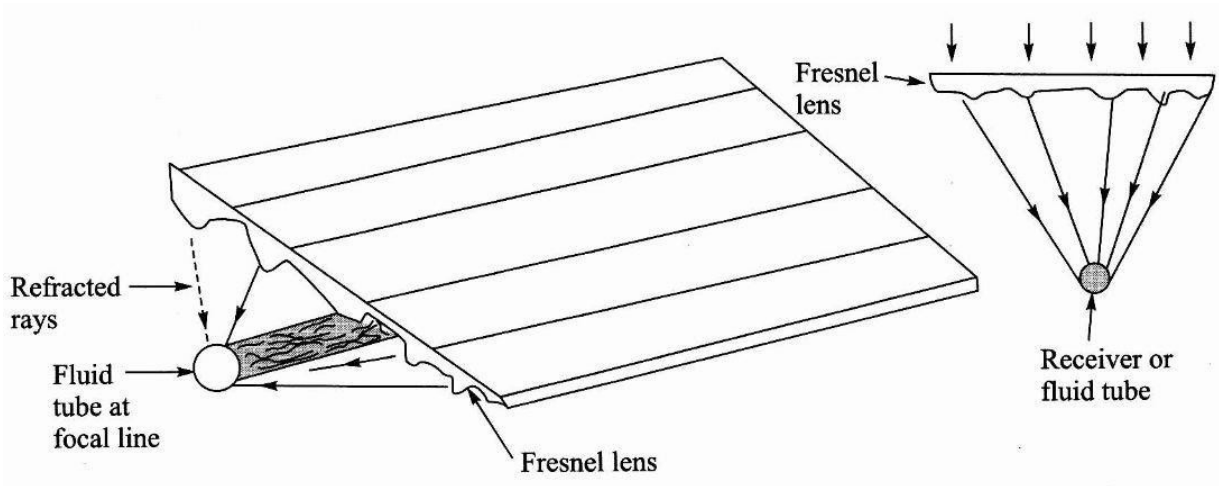


Figure 3.8 Linear Fresnel Collector

Circular Fresnel Collector

- What do you understand by circular Fresnel collector? Explain with neat sketch.

The principle of working of this type of collector is similar to the linear Fresnel collector and the only difference is that this type of collector is designed to concentrate the radiation at one focal point instead of line focus. These Fresnel lenses concentrators are used where high concentration of radiation is required, for examples, with silicon solar cell receiver. The concentrator has a number of thin circular zones with fine grooves so designed that the lens

concentrator behaves optically as a thin spherical lens. The sun rays are made to refract and converge at a point as shown in Figure 3.8. The concentration ratio obtained by this concentrator is very high with a value of about 2000.

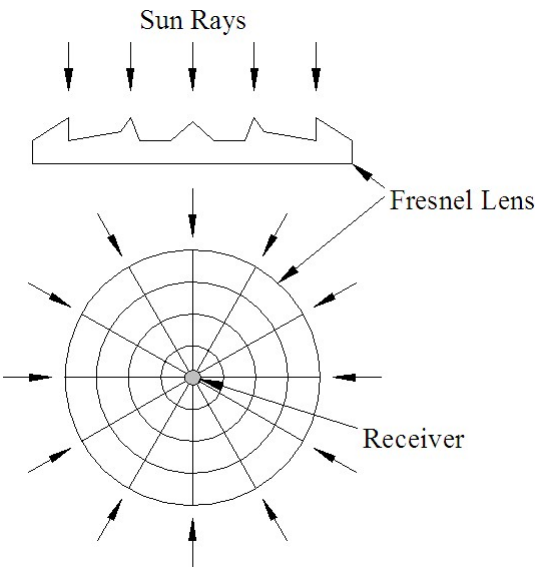


Figure 3.9 Circular Fresnel Lens Collector

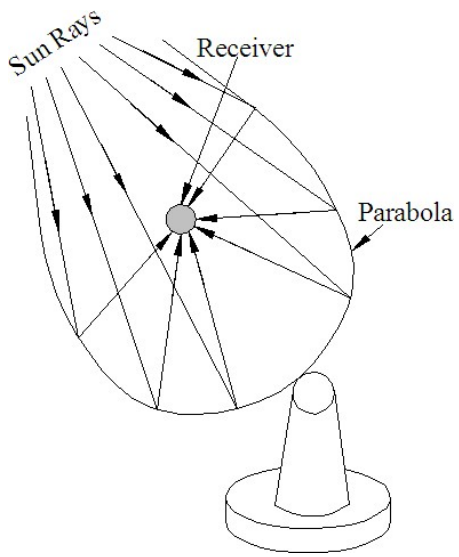


Figure 3.10 Paraboloidal Sish Collector

Parabolodial Dish Collector

- Describe any kind of point focus collector.
- Describe any kind two axis-tracking for point focus collector.
- Write a short not on parabolodial dish collector.

A point-focus collector has a dish of the shape of a paraboloidal, that is, the surface produced when a parabola is rotated about its axis. The paraboloidal surface can concentrate all incident radiation parallel to its axis to a point focus where the receiver tube is positioned. In order to ensure proper incidence of radiation, the parabolic dish collector should be provided with two axes tracking: (i) by rotating the support structure about the vertical axis for dish alignment and (ii) the dish is rotated about a horizontal axis for elevation tracking as shown in Figure 3.10. This type of collectors can have concentration ratio ranging from 10 to 1000 which helps to produce temperature up to 3000°C.

Hemispherical Bowl Mirror Concentrator

- Describe a hemispherical bowl mirror concentrator. How does its tracking differ from that of paraboloidal point focus collector.

The hemispherical bowl mirror concentrator is a point focus concentrator in which reflector remains stationary and the receiver is made to track about two axes as per the movement of the sun in the sky so that solar radiation can be converged at the receiver kept at the focal point. The hemispherical fixed mirror, absorber with two axes tracking system and supporting structure of the collector is as shown in Figure 3.11. All the sun rays entering the hemisphere after reflection are concentrated at focal point. The absorber should be moved in such a way that it is always at the converging point of the sun rays after the reflection.

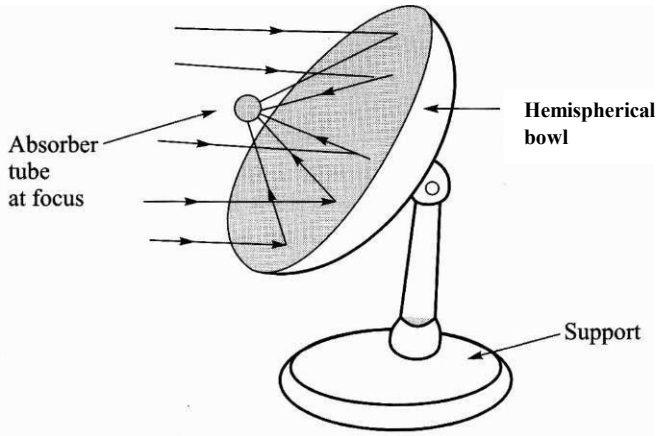


Figure 3.11 Hemispherical Bowl Mirror Concentrator

Central Tower Receiver Collector

- What do you understand by central tower receiver collector? Explain briefly.

In this type of collectors, the receiver is located at the top of a tower and solar radiation is reflected on it from a large number of independently controlled flat mirrors called heliostats. The heliostats can be moved independently about two axes so that the reflected solar radiation is always directed towards the absorber mounted on the tower as shown in Figure 3.12. The heliostats are spread over a large area on ground surrounding the absorber mounted on the tower. The number of heliostats can be as high as thousands and they simultaneously track the sun to reflect the solar radiation from all sides on the receiver. These heliostats together act as a very large paraboloidal dish collector. The concentration ratio as high as 3000 can be obtained by this point type concentrator called central tower receiver collector.

The solar radiation at the receiver is converted into heat, which is transported to a heat engine or any other device for use.

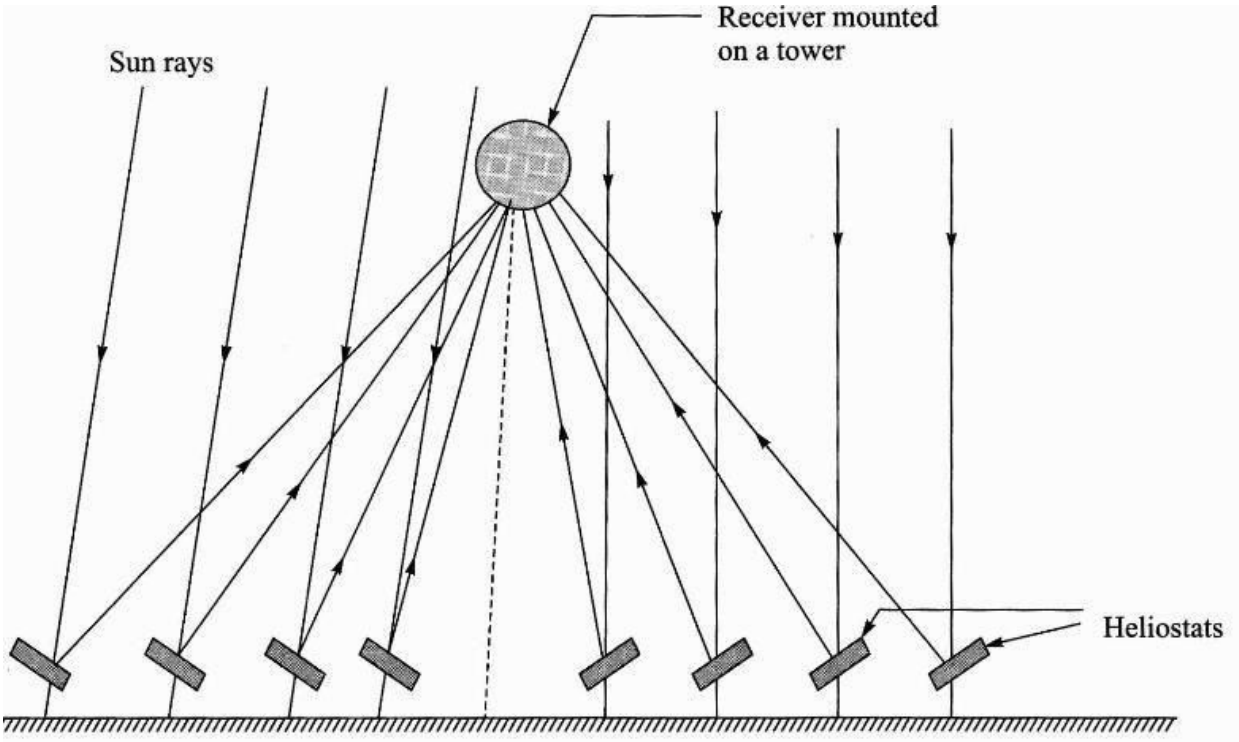


Figure 3.12 Central Tower Receiver with Heliostats

Comparison Between Flat and Focusing Collectors

- Differentiate between flat plate and focusing collector.

The difference between flat plate collectors and focusing collectors are as follows

SL No	Flat Plate Collectors	Focusing Collectors
01	Absorber area is large	Absorber area is small
02	Concentration ratio is 1	Concentration ratio is ranging between 3 & 3000
03	Low temperature range usually <70°C	Temperature range is up to 3000°C
04	It collects both beam and diffuse radiation	It collects mainly beam radiation
05	Simple in construction	More complex in construction
06	It does not requires tracking system	It requires tracking system
07	Application limited to low temperature application	Application such as power generation
08	Suitable in all the days in a year and at all locations	Suitable for where there are a more clear days in a year

Orientation of Flat Plate Collector

To reduce the losses owing reflection of incident radiation from the absorbing surface, it is essential that incident radiation should strike the absorbing surface at the right angle. But the incident radiation changes its direction as per the movement of the sun in the sky. The angle of incidence of the sun rays also depend on (i) latitude of the place, (ii) time of the day and (iii) time of the year. Ideally, the collector should follow the sun in order to get maximum radiation. However, this will require a huge amount of electrical energy for tracking device to keep the collector facing the sun as it moves in the sky. It is neither advisable nor economical in the context of flat plate collector having low energy output. The flat plate collectors are, therefore, kept facing south so that the maximum amount of energy can be extracted for all places in the northern hemisphere. The collector is also always kept inclined to horizontal position, with optimum inclination facing the sun so that maximum solar radiation is received throughout the day. The optimum inclination is kept as follows:

(i) In summer, inclination = latitude - 15°
(ii)In winter, inclination = latitude + 15°
(iii)Round the year, inclination = latitude

Solar Energy Storage:

- What do you understand by solar energy storage?
- Why the storage of solar energy is is necessary?

The solar energy is generally transformed into thermal or electric energy using solar devices. The solar energy is, however, available during sunshine hours and the demand of thermal or electric energy may also exist during non-sunshine hours. Also, the maximum availability of solar energy may not coincide exactly with the demand of thermal or electric energy. The availability of solar energy is sometimes low for several days due to cloudy days, resulting in the substantial lowering of the output of thermal and electric energy from the solar radiation. Hence, it is essential to store energy output (thermal and electric) from solar devices during high insolation (in=incident, sol=solar and ation=radiation) times which is used after words to meet the thermal and electric load demand during peak demand times. During low insolation times, solar energy storage system enables delivery of more power than what is

generated by the solar electric or thermal plant, and so it enables to match the generation of energy with the load demand.

Classification of Solar Energy

- How do you classify the solar energy storage? Explain briefly.

The solar energy storage systems can be classified as follows:

- **Thermal energy storage:** Thermal energy storage can be (i) sensible heat storage by the virtue of heat capacity and the change in temperature of the material and (ii) latent heat storage by the virtue of latent heat necessary to change the phase of the storage medium.
- **Chemical Energy Storage:** Lead acid batteries are the most commonly used means in chemical energy storage system. The advantages are (i) good working efficiency (up to 80%), (ii) low cost, (iii) rapid change from charging to discharging mode and (iv) slow discharge rate. A storage battery takes electrical energy generated by solar radiation and stores it as chemical energy. It later supplies the electric energy by converting this stored energy.
- **Electrical Energy Storage:** A capacitor is used to store electrical energy in an electrostatic field when it is charged. The capacitor of large capacity is required to store a significant amount of energy.
- **Hydrogen Energy Storage:** The electrical energy is used to decompose water by the electrolysis reaction into hydrogen and oxygen. These substances can be recombined to release the stored energy when required.
- **Electromagnetic Energy Storage:** The electrical energy is used to store energy in a magnetic field. The resistance of the coil wire is made almost negligible so that the stored energy in the coil is not dissipated out and stored energy in the magnetic field can be maintained indefinitely. The electromagnetic energy storage requires the use of superconducting materials. These materials develop almost zero resistance to electricity flow when cooled below a critical or transition temperature. This method of storing electromagnetic energy is also called super conducting magnetic energy storage (SMES). The electric energy can be recovered when coil is discharged.
- **Biological Energy Storage:** The solar energy is stored in plants by a process known as photosynthesis. Photosynthesis is the process in which organic compounds are formed in green plants using carbon from

atmospheric carbon dioxide in the presence of sunlight. The plants on decaying form biomass which can be converted into various types of solid, liquid and gaseous fuels.

Sensible Heat Storage

- What are the main advantages and disadvantages of sensible heat storage with water as storage media? Compare them with those of solid media storage.

Thermal energy is stored in these types of storage by virtue of heat capacity and temperature difference developed during charging and discharging. The temperature of the storage material rises when thermal energy is absorbed and temperature drops when thermal energy is taken out. In this storage, the charging and discharging can be performed reversibly for an unlimited number of times. The sensible heat storage can be liquid media storage and solid media storage. Water is considered as the most suitable media for storage below 100°C. Liquids such as oils, liquid metals and molten salts are also used as liquid media storage.

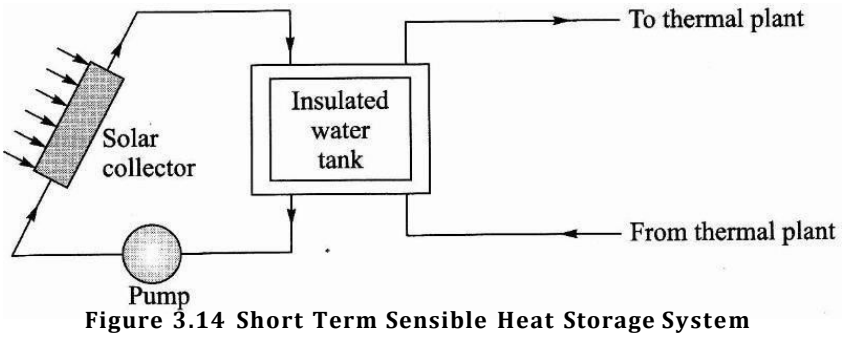


Figure 3.14 Short Term Sensible Heat Storage System

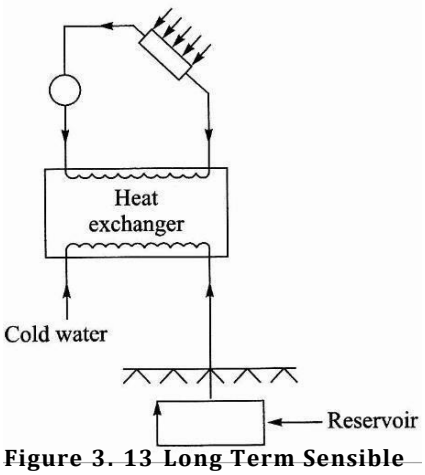


Figure 3. 13 Long Term Sensible Heat Storage System

The water thermal energy storage can be short term and long term. A short-term thermal energy storage system has a well-insulated storage tank as shown in Figure 3.13. The storage in such tank is economical for few days only as heat losses over long duration make the storage uneconomical. Long-term sensible heat storage by water is possible in underground reservoirs having special insulation. In this system, water is heated in charging mode by passing it through a heat exchanger and then it is stored in an underground reservoir. In the discharge mode, the hot water is made to flow back through the heat

exchanger, where it releases the stored energy as shown in Figure 3.14 but with reverse circulation.

Advantages:

- It is abundantly available.
- It is inexpensive.
- It has high specific heat which enables to store more heat per unit mass.
- It has low viscosity requiring less energy to pump through the pipe system.
- It can be used for both storage and working medium.
- It is stable.
- It has no harmful effect.

Disadvantages:

- It has limited temperature range of 0-100°C.
- It results in the corrosion of pipes.
- It can leak easily as it has low surface tension.

Solid Media Storage or Packed Media Storage

This type of storage has a bed of loosely packed solid materials such as rocks, sand, concrete, pebbles and metals to store sensible heat. A fluid such as air is circulated through the bed to add or remove heat from the storage. This type of solid media storage has no limitations such as (i) low temperature due to freezing and (ii) high temperature due to vaporizing as applicable in the case of liquid media storage. A typical packed bed storage unit is shown in Figure 3.15. It consists of a container, a screen to support the bed, inlet duct and outlet duct. The charging or adding of heat is done by passing hot air through the bed in one direction and the removable of heat is done by passing the normal air through the bed in the opposite direction.

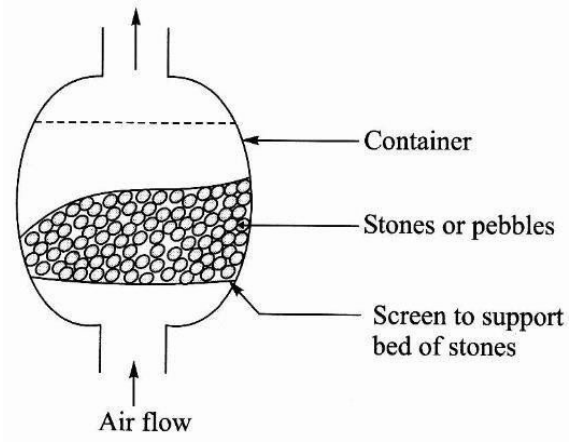


Figure 3.15 Solid Media Storage

Advantages

- Stones or pebbles are abundantly. Available
- Low cost
- Non-combustible
- Easy to handle
- Possibility of high storage temperature
- No freezing point during heat removal
- No corrosion problem
- No requirement of heat exchanger

Disadvantages:

- The size of the storage container should be large
- Simultaneously charging and discharging of energy is impossible
- Large pressure drop needs high capacity air blower

Latent Heat Storage

- Why solid-gas and liquid-gas phase changes are not considered suitable for latent heat storage?
- What are the main problems associated with the use of slat hydrate as latent heat storage.

In the latent heat storage, heat energy is stored by virtue of latent heat which is required to bring about phase change of storage medium. The heat required to bring about phase change of a material is much larger compared to sensible heat change of the same material. The phase change of a material also involves absorption or release of a large quantity of heat energy at constant temperature, which is impossible in the case of sensible heating and cooling. Therefore, latent heat storage system is more compact for certain heat storage compared to sensible heat storage system. The phase change which can be used for storage system are solid-solid, solid-gas, solid-liquid and liquid-gas. Solid-gas and liquid-gas transformation involves large volume changes, thereby making such storage systems impractical and complex. However, solid-solid transition involves transformation of the material from one crystalline form to another, thereby resulting in the transformation with small volume changes. Hence, such storage systems are practical and preferred in spite of small changes in latent heat possible during transformation.

SOLAR POND:

- With the help of schematic diagram, explain the working of solar pond electric power plant.
- What is meant by solar pond? Explain.
- Describe the working of a solar pond.
- Explain the principle of and working of solar pond.

Principle: In ordinary pond, when water is heated up by the sun rays, the heated water rises to the top of the pond. The hot water loses heat to the atmosphere, and so the net temperature at the top of the pond remains nearly at atmospheric temperature. The solar pond technology ensures that heated brine water remains at the bottom of the pond due to more brine concentration and density in it.

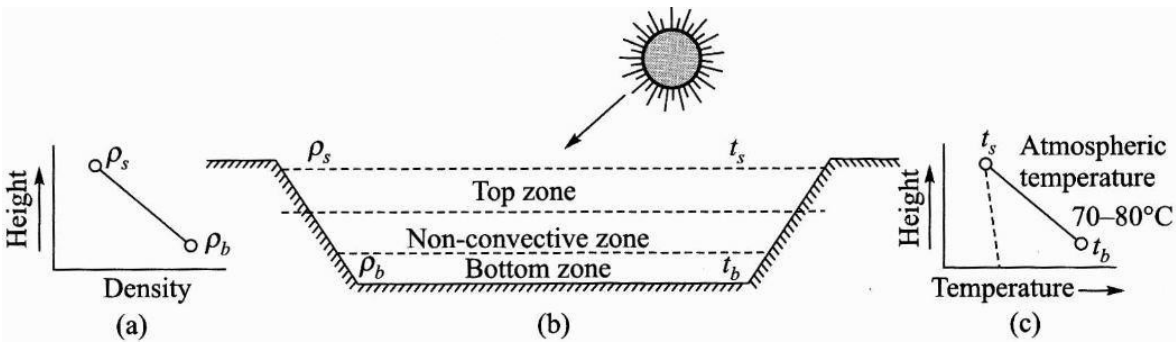


Figure 3.16 The Concept of Solar Pond (a) Variation of density, (b) The three zones in the pond, (c) Variation of Temperature

The solar pond serves the dual purpose of a large flat collector and a thermal storage system, It consists of a large size brine pond (depth of about 1m) which has salt concentration gradient in such a way that the most concentrated and dense part of the brine solution is at the bottom of the pond and brine concentration gradually reduces from bottom to top of the pond based on the variation of brine solution density. A solar pond has three zones as shown in Figure 3.16. The top zone is surface zone which has the least salt content and its temperature is the atmospheric temperature. The bottom zone has the maximum salt content and it has a high temperature (70-85°C). This is the zone that collects and stores the solar energy as heat energy. In between these two zones there is the gradient non-convective zone.

The hot brine solution from the bottom of solar pond is taken out without disturbing the brine gradient existing in the solar pond. This solution is taken to heat exchanger to remove heat from the brine solution by evaporating a

refrigerant in the evaporator. These vapors are used to run a turbine which is coupled to a generator to generate power. The refrigerant vapors exiting from the outlet of the turbine are condensed to liquid state in a condenser and pumped to heat exchanger. Solar pond electric power plant is shown in Figure 3.17.

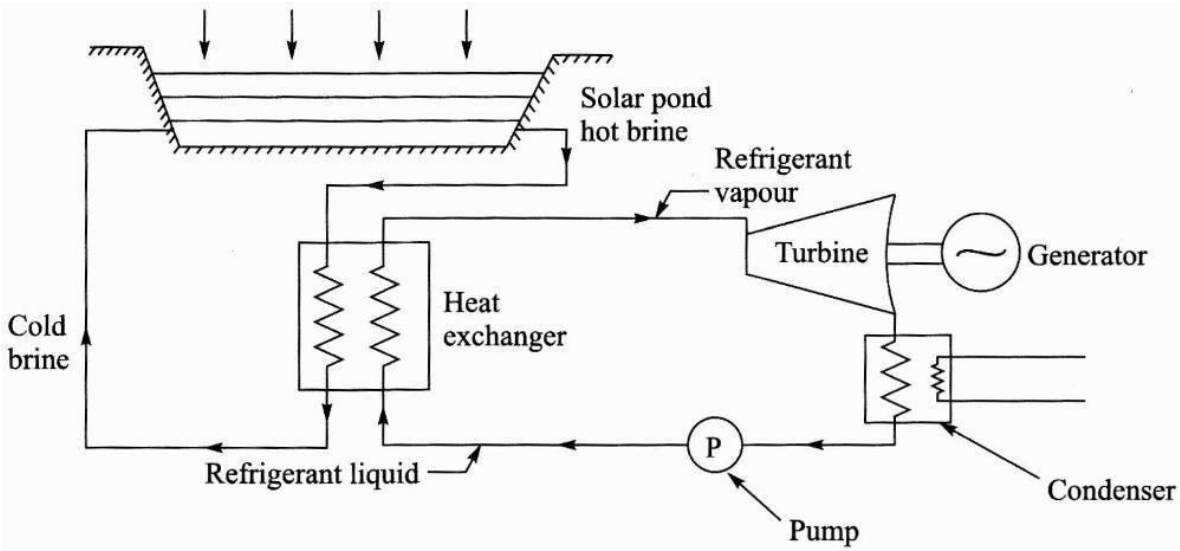


Figure 3.17 Layout of Solar Pond Electric Power Plant

Solar Water Heater:

- With the help of neat sketch, explain the working of a solar water heater.
- Describe the working of solar water heating system.
- With neat sketch explain working of a domestic water heater.
- Explain how does a natural circulation water system works?

A small capacity water heating system with natural circulation is as shown in Figure 3.18. It is suitable to supply hot water for domestic purposes. It has two main components which include (i) flat plate collector to convert solar radiation into heat energy and (ii) water storage tank to store hot water. The tank is located above the level of collector. Heat is transferred to the water in the solar collector and hot water rises to flow in the water tank. The hot water enters the top of the water tank and cold water from the water tank moves out from the bottom of the tank so as to enter the inlet of the collector. The natural circulation of water is established from the collector to water tank and then from water tank to the collector. The hot water for use is withdrawn from the top of tank, which is replaced by cold water entering at the bottom of the tank. Water heating system is also provided with an auxiliary heating

system so that the system can also work during cloudy and rainy days when sufficient solar radiation is unavailable.

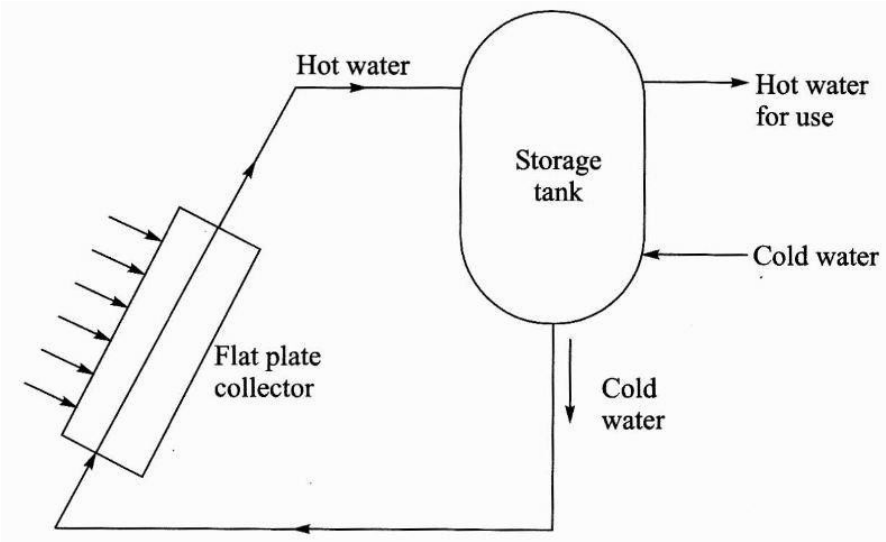


Figure 3.18 Small Capacity Water Heating System with Natural Working System

Solar Thermal Pump:

- Explain the working of the solar thermal pump with the help of a neat sketch.
- What are the features of solar energy which make it attractive for water pumping in irrigation?
- Explain the principle of solar pumping.

Solar pumping utilizes the mechanical power generated by the solar radiation to run the water pump. Solar energy offers several beneficial features which make its utilization in irrigation pumping quite attractive. The features are as follows:

- The need for pumping arises most during the summer months when solar radiation is intense.
- Pumping can be carried out intermittently without any problem.
- Surplus pumped water can be stored in a reservoir or tank.
- The requirement of water decreases during periods of low radiations when solar pumping decreases. Evaporation losses reduce during cloudy days. Rainwater is also available during rainy days.
- There is relatively inexpensive running and maintenance cost.

The solar pump is similar to solar heat engine working in low-temperature range. The source of heat is a solar collector. The heat is transported to a heat exchanger where heat is transferred to a refrigerant of low boiling point. The refrigerant evaporates and high-pressure vapor is taken to a turbine to do useful mechanical work by running the solar pump as shown in the Figure 3.19. The outlet refrigerant vapor from turbine is condensed and taken to heat exchanger using feed pump for reuse.

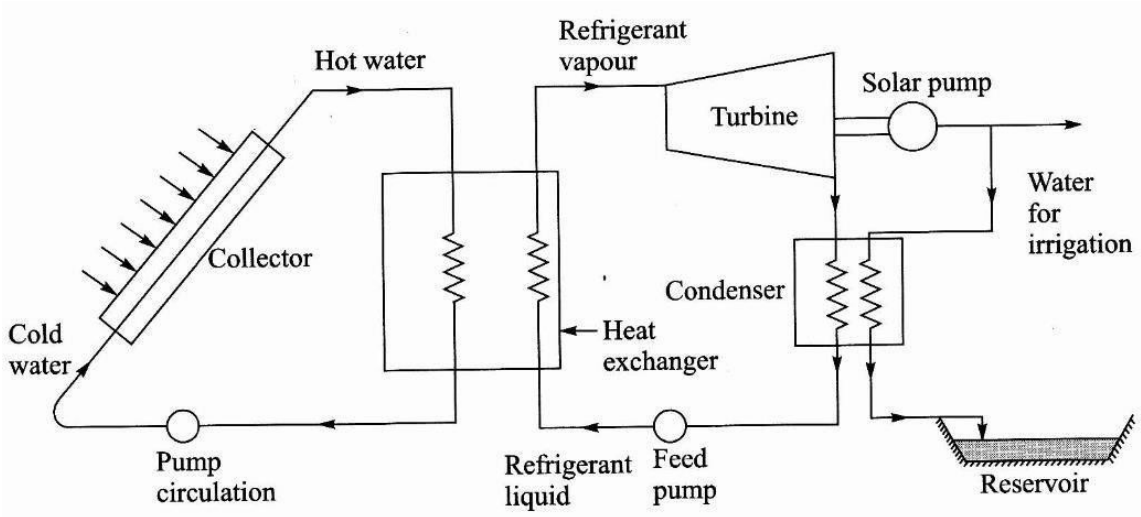


Figure 3.19 Solar Water Pump

<u>Solar Furnace</u>:

- Explain the working of a solar furnace with the help of a neat sketch.
- What are the main advantages and disadvantages of a solar furnace?
- What is the maximum temperature obtained in a solar furnace? explain.

Principle: Solar furnace is used to study the properties of the materials, such as physical, mechanical, chemical & electrical properties at high temperatures. The focusing type solar collectors can concentrate solar radiation over a small area in a furnace for heating of materials being tested. It is possible to obtain high temperatures which can be about 3500°C.

The solar furnace has basically two main components: (i) a concentrator with arrangement to position testing materials at its focus and (ii) a system of a large number of small heliostats. The large number of heliostats are located and positioned in such a manner that they direct solar radiation onto a paraboloidal collector (Figure 3.20). The solar radiation after reflection from the heliostats moves parallel to the optical axis of the concentrator. The heliostats

are provided with the systems of sun tracking. The concentrator focuses the incoming solar rays on to the test material to heat up.

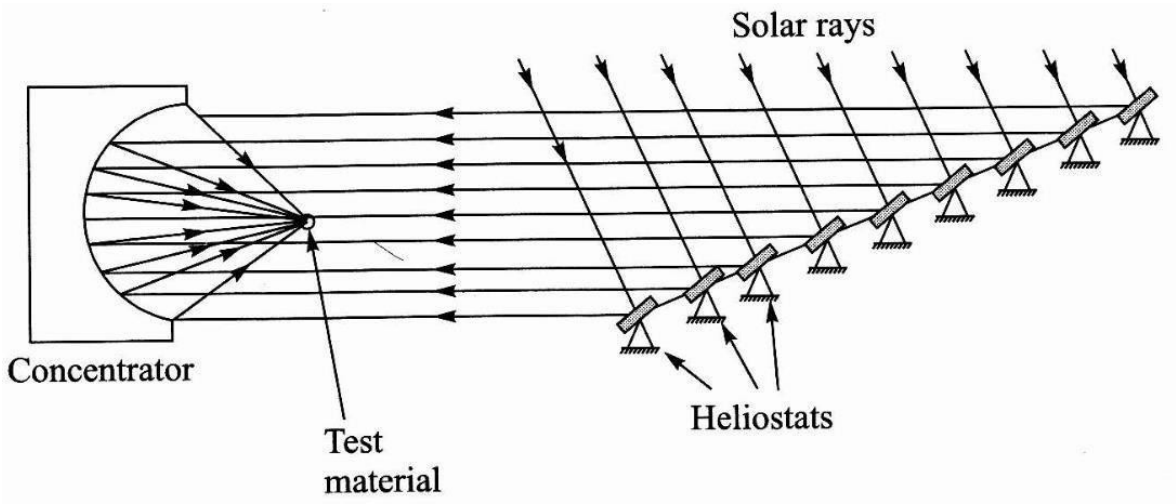


Figure 3.20 Solar Furnace Using Heliostats and Paraboloidal Concentrator

The advantages of solar furnace are as follows.

- It gives pure heating without contamination.
- It provides easy control of temperature.
- No adverse effect is produced on the test material by the sun rays.
- It has simple working principle.
- It provides an easy observation of test material while heating.
- It gives high rate of heating by intense radiation concentrated at a point.

The disadvantages of solar furnace are as follows.

- It can be used during sunshine hours.
- The cost of equipment is high.
- Materials with small area can be only heated and tested.

Solar Passive Space Heating:

- What do you understand by solar passive heating?
- How is passive heating assured by building design?
- Write briefly about solar house.
- With neat sketch explain briefly about Troumbe wall or thermal storage wall.

Solar energy can be used for passive heating of buildings to maintain comfortable temperature inside the buildings. Passive heating of buildings does not require any mechanical device. This heating consists of natural processes such as convection, radiation and conduction which are used to transport heat in the space. The heating necessitates a suitable building design to ensure natural flow of heat in the space inside building. Such specially designed building is called solar house.

In the northern hemisphere, the sun rays come from south direction. Hence in order to achieve solar passive heating in cold regions, south facing wall is made thick using concrete or stones to store the maximum heat energy from the incident solar radiation. The entire south wall is further provided with a plastic or glass sheet covering with an air gap in between the wall and the sheet covering. The incident solar radiation after passing through the sheet covering is absorbed by the thermal storage wall. The warm air in air gap rises and enters into the space inside the building to be heated as shown in Figure 3.21. The warm air enters into the space from the upper inlet vents and cold air is removed from the space from the lower outlet vents.

Thermal storage wall is vertical in position and is well known as Troumbe wall, made up of concrete brick, or other masonry some 0.3m or more thick. Dr. Felix Troumbe was developed this concept. The distance between glazing (Glass) and concrete wall is about 10 to 20 cm apart, and it is painted black, which serves as both radiation absorber and a heat storage system.

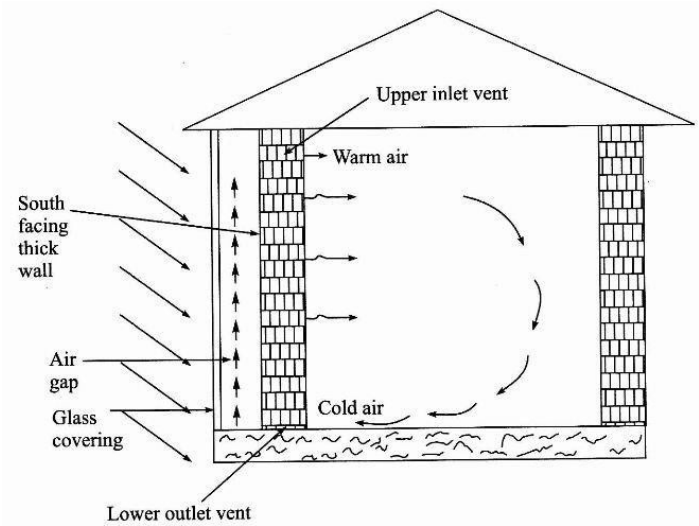


Figure 3.21 Solar Passive Heating

There is another method to provide solar passive space heating, which is shown in Figure 3.22. In this method, a flat plate collector is provided to face south. The collector is provided with rock bed type storage system. During sunshine hours, the collector transfers and stores heat energy from incident solar radiation into the rock bed storage system. The available stored energy in the rock bed is used later at night when air is passed through the rock bed, and so warm air enters into the space to be heated.

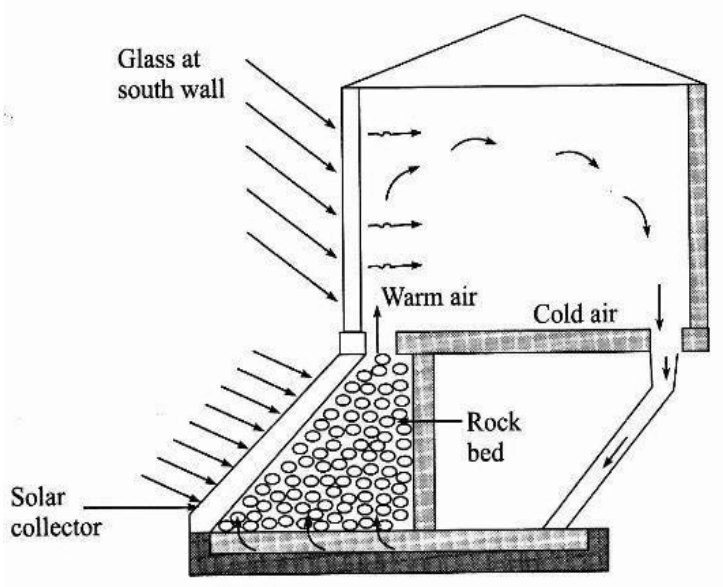


Figure 3.22 Passive Solar Heating Using Solar Collector

<u>Solar Passive Cooling</u>:

- For solar passive space cooling, the best approach is to reduce unnecessary heat loads entering the space inside the building. Comment.

The heat tends to enter a building in the following ways:

- Direct sunlight heat which can be reduced by using shading and providing venetian blinds to glass windows and doors.
- Conduction of heat through walls, roof and floor. It can be reduced by providing insulation. Maximum heat is conducted through the exposed roof which has to be provided a false ceiling with good insulating materials to reduce the conduction of heat from it.

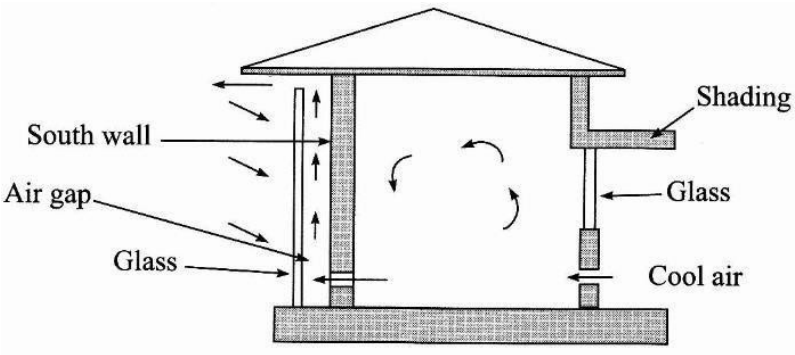


Figure 3.23 Solar Passive Cooling Through Ventilation

- Infiltration of outside hot air. It can be reduced by proper sealing of the space and reducing the openings of doors and windows.

The methods to reduce or prevent heating of the space are as follows:

- Shading of glass area and the walls.
- Providing air circulation or ventilation so that warm air is driven out and cool air from outside is sucked into the space using chimney effect as shown in a Figure 3.23.
- Providing a pond on the roof to reduce radiation heating and achieve cooling below the pond.
- Providing black plastic bags on a metallic roof which helps in radiating out the heat from the space during night-time.
- Providing ground coupling or basement construction to maintain temperature of the space close to ground temperature.
- The ground temperature is always lower than surrounding atmospheric temperature.

Solar Vapor Absorption Refrigeration and cooling system:

- Explain a method of active cooling of a space by solar radiation.
- Compare the relative merits and demerits of lithium bromide and water aqua ammonia vapor absorption cooling system.
- Explain the solar vapor absorption system for cooling.

A simple solar operated absorption refrigeration system to cool a space is as shown in Figure 3.24. The hot water transported from a flat plate collector is passed through a generator which is a heat exchanger. The heat is transferred to a refrigerant and absorber solution. The refrigerant can be ammonia or water while absorber is water or lithium bromide which generates refrigerant vapors at high pressure. The high-pressure vapors are condensed into high- pressure liquid in the condenser. The high-pressure refrigerant liquid is throttled to low pressure and temperature by an expansion valve. The low pressure refrigerant takes heat from the evaporator and vaporizes, thereby cooling air or water which can be used for cooling the space inside the building. The refrigerant vapor is ultimately absorbed into the weak solution taken from generator to the absorber, thereby converting it into strong solution of the refrigerant. The strong solution is pumped from the absorber to the generator for the repeat of the refrigeration cycle.

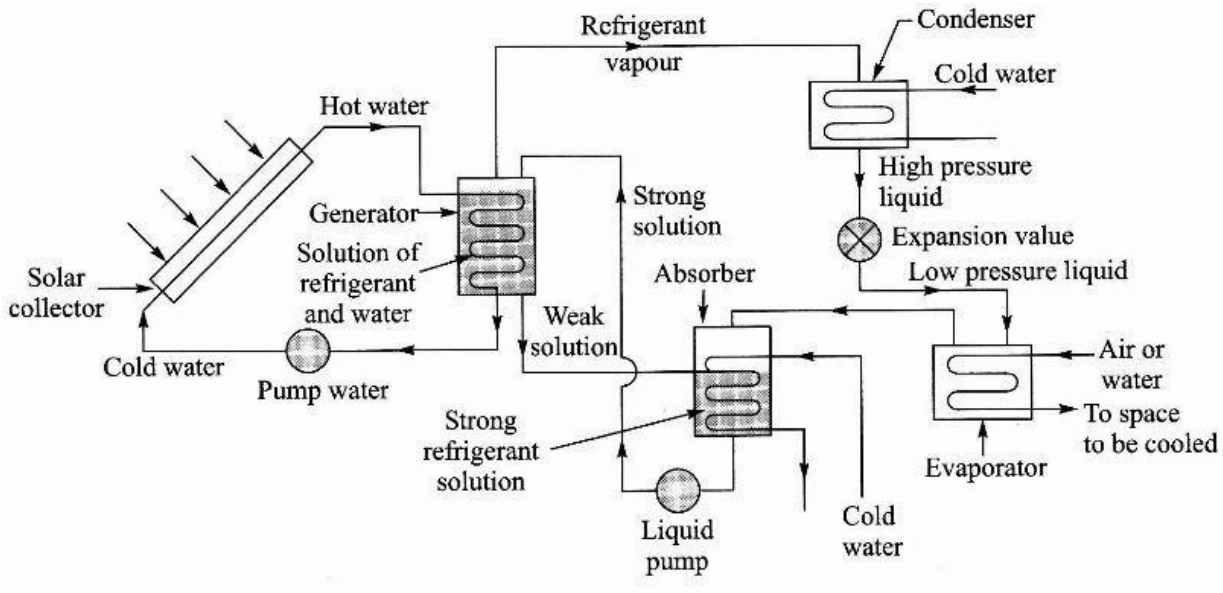


Figure 3.24 Solar Absorption Refrigeration System.

Lithium bromide-water system

Water is refrigerant and lithium bromide is absorber. The absorber has pressure of 0.1 atm and temperature of 90°C while evaporator has pressure of atm and temperature of 4°C.

Merits

- It is a comparatively simple system.
- It has high coefficient of performance.
- It requires less power for pumping water from absorber to generator due to lesser pressure in the generator.
- Water as refrigerant has more latent heat of vaporization.
- Lithium bromide is non-volatile which helps to prevent water vapor from going out of generator to condense.
- Solution is non-toxic.
- Solution is non-inflammable.

Demerits

- As it can develop low temperature of 4°C only in evaporator. The system can be used for only air conditioning purpose.
- The solution is corrosive.

- Maintaining very low pressure in the evaporator and absorber is problematic.
- Condenser has to be water cooled. Air cooling of condenser is not possible.

Aqua-ammonia absorption system

It has ammonia as refrigerant and water as absorber. The generator has pressure of 10 atm and temperature of 120°C, while evaporator has pressure of 1 atm and temperature of -5°C.

Merits

- It is suitable for both air conditioning and refrigeration.
- Condenser can be air or water cooled.
- The absorber is water, which is non-toxic and inflammable.

Demerits

- A rectifier is requiring separating water entering into condenser.
- High pumping power to pump refrigerant from the absorber to the generator is required.
- Ammonia is inflammable.
- Ammonia is toxic.

Solar Vapor Compression refrigeration and cooling system:

- Describe a solar cooling system based on vapor compression system.
- Can a vapor compression system be used for heating?
- What is solar air conditioning?

Vapor compression system can be used for both cooling and heating. If the vapor compression system takes heat from space and releases to atmosphere, it is working as cooling system. On the other hand, if the vapor compression system takes heat from atmosphere and releases the same into the space, it is working as heat pump. The vapor compression system working with solar radiation to cool a space is shown in Figure 3.25. Solar power is converted into mechanical work using turbine which then runs a compressor coupled with it. The compressed refrigerant is expanded into evaporator, providing the requisite cooling.

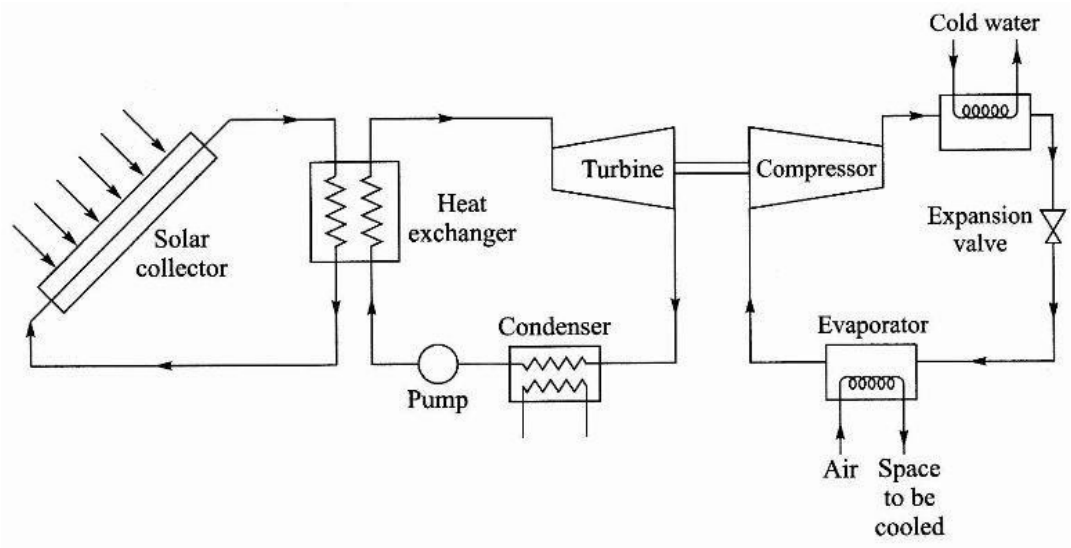


Figure 3.25 Solar Vapor Compression Refrigeration system

Solar Cookers:

- Describe a solar cooker.
- What is the main advantage of using a glass cover in a box-type cooker?

A solar cooker consists of (i) an insulated box of blackened aluminum in which utensils with food materials can be kept, (ii) reflector mirror hinged at one side of the box so that the angle of reflector can be adjusted and (iii) a glass cover consisting of two layers of clear window glass sheets which also serves as the box door as shown in Figure 3.26.

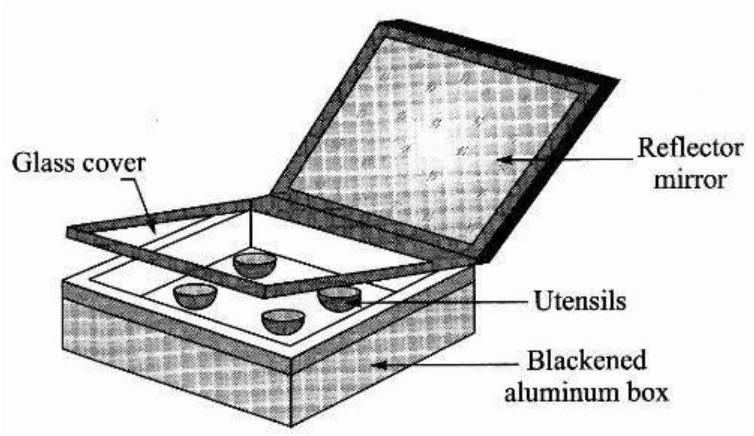


Figure 3.26 Solar Cooker

The box is kept in such a way that solar radiation falls directly on the glass cover and reflector mirror is also adjusted in such a way that additional solar radiation after mirror reflection is also incident on glass cover. The glass cover traps heat owing to the greenhouse effect, that is, short-wavelengths radiation can pass inside the box but long-wavelengths radiation coming out

from the box is entrapped in the box, thereby providing more heating effect. The air temperature obtained inside the box ranges from 140°C to 160°C. This provides sufficient heat for boiling and cooking purposes.

Solar Distillation:

- What do you understand by solar distillation? Explain briefly.
- How does a solar still works?

The process to convert saline water into pure water using solar radiation is called solar distillation. A solar device used for this purpose is called solar still. A solar still consists of a shallow blackened basin filled with saline or brackish water to be distilled. It is covered with sloping transparent roof as shown in Figure 3.27. The sun rays can pass through transparent roof and these rays are absorbed by the blackened surface of the basin, thereby increasing the temperature of water. The water in basin evaporates due to solar heat and rises to the roof. The water vapour cools down and condenses at the undersurface of the roof. The water drops or condensed water slip down along the sloping roof. The condensed water is collected by the condensate channel and drained out from the solar still.

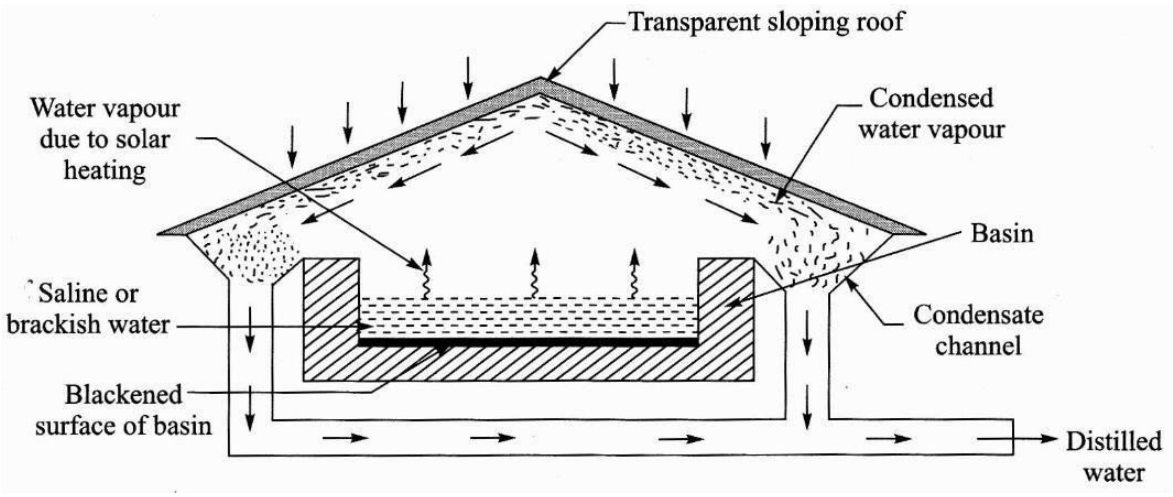


Figure 3.27 Working of Solar Still

Solar Thermal Power Plant:

- Describe a working of solar power plant.

The solar thermal power plants can use different systems, such as

- Low temperature solar power plant using flat plate collectors.
- Low temperature solar power plant using solar pond.
- Medium temperature solar power plant using focusing collectors.
- High temperature solar power plant which can be.

  - Distributed collector collected system called solar farms.
  - Central receiver system or tower power plant.

The principle of these plants is the same, which involves transportation of heat generated by the absorption of solar radiation. In medium and high temperature solar plants, steam is generated which is made to run a turbine with a generator coupled to it. In a low temperature solar system, transported heat is used to (i) generate vapor of low boiling point refrigerant using a heat exchanger and (ii) to run a turbine coupled with generator using refrigerant vapor. A central tower receiver solar power plant is shown in Figure 3.28.

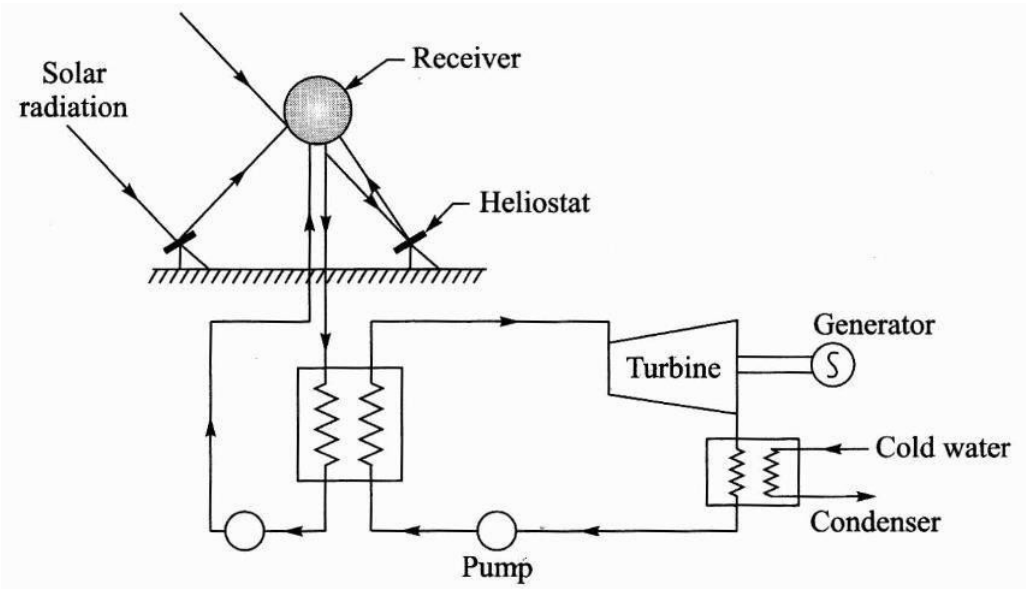


Figure 3.28 The working of a central tower receiver plant

<u>Solar Green House</u>:

- What is green house? Write a short note on it.
- How is adequate supply of carbon dioxide maintained in a green house?
- What is the purpose of using double layers of transparent glass sheet in a green house?

A greenhouse is a shed or enclosure in which a proper environment is provided to enable the growth and production of vegetables and flowering

plants even during adverse and severe climatic conditions prevailing outside. Any vegetable or flowering plants can be grown throughout the year if suitable environmental conditions are provided.

In a greenhouse, visible light, carbon dioxide and water are provided as required for photosynthesis process. The photosynthesis process can be given as

$$\text{Light energy} + CO_2 + \text{water} = \text{Carbohydrate} + O_2$$

The carbohydrate produced in photosynthesis is used by plants during respiration process for growth. The respiration process can be given as

$$\text{Carbohydrate} + O_2 = CO_2 + \text{energy} + \text{water}$$

A typical greenhouse is shown in Figure 3.29. To ensure enough sunlight inside the greenhouse, sufficient glass or transparent plastic sheet is provided in roof and walls in the greenhouse facing the sun. For roof, two layers of glass or plastic sheets are provided with small air gap in between to obtain proper thermal insulation. The air gap helps in entrapping the solar radiation inside the greenhouse as it prevents the passing out of long-wavelength radiation from inside of the greenhouse to the atmosphere. Adequate presence of carbon dioxide is ensured by (i) supplying outside air (ii) using organic manure (iii) combustion of sulphur-free fossil fuels and (iv) carbon dioxide gas.

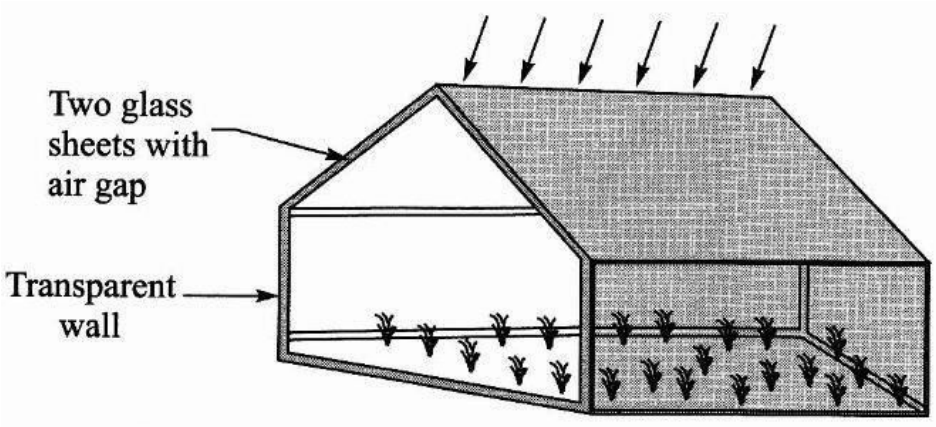


Figure 3.29 Green House for Cold Climate

Part B

Unit – VI:

Tidal Power: *Tides and waves as energy suppliers and their mechanics; fundamental characteristics of tidal power, harnessing tidal energy, limitations.*

Ocean Thermal Energy Conversion: *principle of working Rankine cycle, OTEC power stations in the world, problems associated with OTEC.*

Geothermal Energy Conversion: *Principle of working, types of geothermal station with schematic diagram, geothermal plants in the world, problems associated in the geothermal conversion, scope of geothermal energy.*

6.1 Introduction:

Tides are produced by gravitational attraction of the moon and the sun acting on the rotating earth. Tides are periodic rise and fall of the water level in the oceans due to various positions of rotating moon and sun. Oceans cover nearly 71% of earth's surface. The water level difference is caused in oceans due to the tides and tides contain a large amount of potential energy. The difference in the level between the high and the low tide is called the tidal range and tidal range of 5-15 m can be easily used to drive turbine coupled with generator to generate electric power.

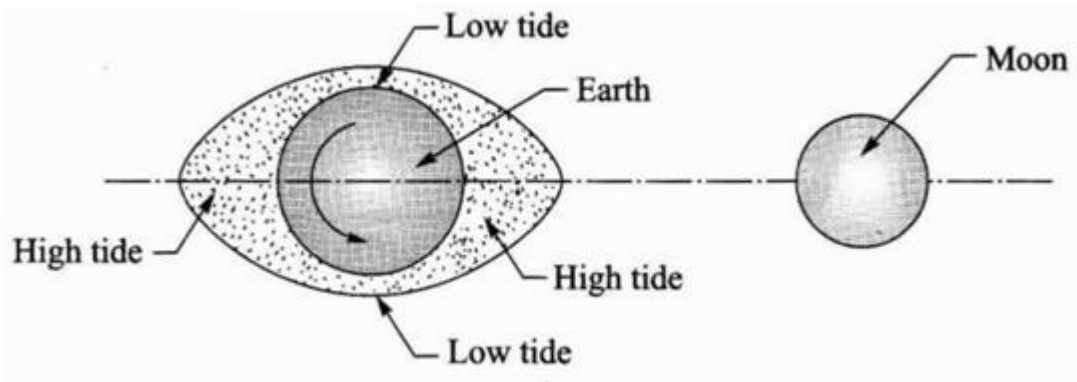
Ocean thermal energy is created by solar energy when ocean water absorbs solar radiation. The absorption of solar radiation causes a moderate temperature gradient to develop in water from the top surface to the bottom of the ocean. This temperature gradient can be utilized using a heat engine to generate power. This process of conversion is called ocean thermal energy conversion (OTEC). The surface water acts as the heat source and the deep water acts as the heat sink and heat engine can operate between these sources and sink. A minimum temperature difference of 20°C is required between source and sink so that heat engine can effectively operate to generate power.

Geothermal energy is the thermal energy present in the interior of the earth. Geothermal energy can be extracted from earth’s interior in the form of heat. Volcanoes, geysers and hot springs are visible signs of the large amounts of heat lying in earth’s interior. The geothermal energy from earth's interior is almost inexhaustible. Although the amount of thermal energy within the earth is very large, but useful geothermal energy can be extracted at only certain suitable sites. It is impossible to extract heat when it is lying at a great depth from the surface. The centre of the earth is estimated to have a high temperature of about 10,000 K. The heat is

generated within the earth due to the decaying process of radioactive isotopes. The molten rock within the earth is called magma, which is nearest to earth's surface with the temperature about 3000°C.

6.2 Origin of Tides:

Tides are produced due to gravitational pulls exerted by both the moon and the sun. As moon is nearer to the earth, the gravitational pull of moon is about 2.33 times stronger than that of the sun. Owing to the gravitational pull of the moon, surface water on the earth facing moon is pulled and raised towards the moon, and so water moves from poles to equator where the moon pull is maximum. This movement of water results in the formation of a high tide at the earth surface facing the moon. A corresponding high tide is also formed on the opposite side of the earth as solid earth is pulled away from the water surface, which results in the apparent rise of water as shown in Figure 6.1.



As moon takes 24 h and 50 min to complete a rotation on its axis, high tide is formed about two times at a place in its one rotation; that is; a high tide

due to moon is formed after a period of 12 h and 25 min. The effect of gravitational pull by the sun is the same, but it is 2.2 times lesser than what is exerted by the moon. Earth revolves around the sun in 24 h. Owing to this slight difference in periods of rotation, solar tides move in and out of phase with lunar tides (Figure 6.2).

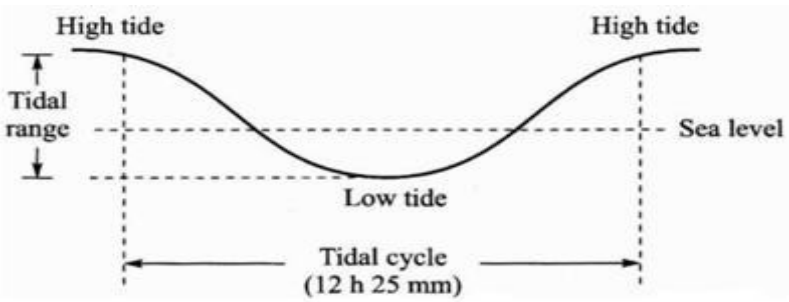
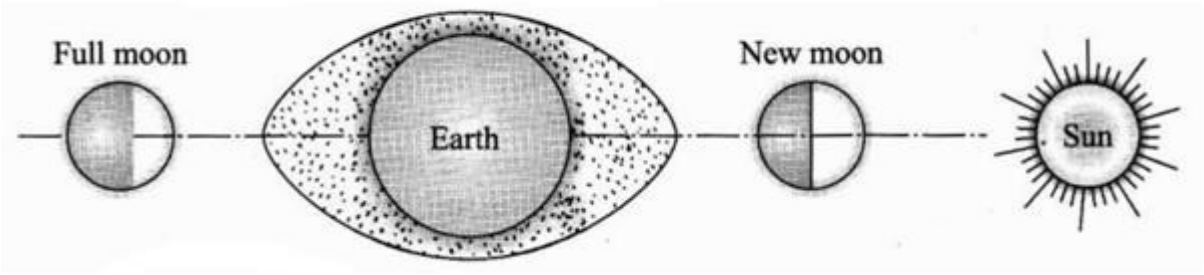


Figure 6.2 Tidal range and tidal cycle.

Spring tides:

When earth, sun and moon are aligned during rotation in a line as shown in Figure 6.3, these celestial bodies produce tides having maximum tidal heights as both solar and lunar tides are in phase. The spring tides are produced twice in a lunar month.



Neap tides:

When sun-earth and moon-earth directions are perpendicular as shown in Figure 6.4, lunar and solar tides are completely out of phase. The celestial bodies produce tides having minimum tidal heights, which are called neap tides. Neap tides are produced twice in a lunar month.

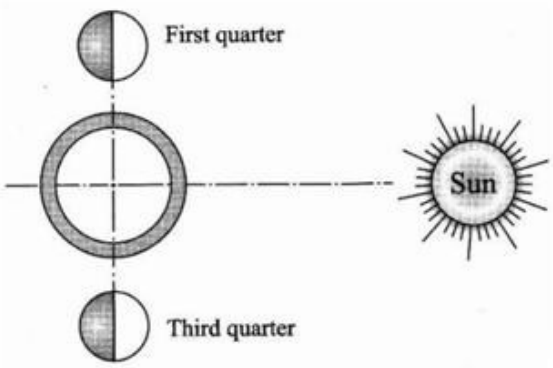


Figure 6.4 Formation of Neap tides.

Tidal variation in lunar month:

The tidal variation resulting in spring and neap tides in a lunar month is shown in Figure 6.5.

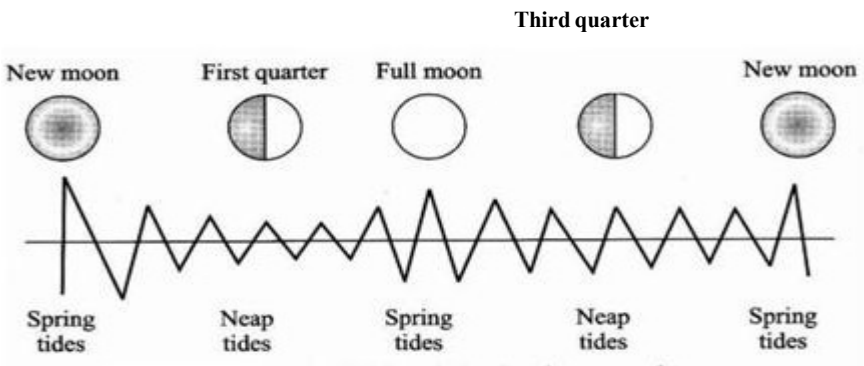


Figure 6.5 Tidal variations in lunar month

6.3 Tidal Energy:

The source of tidal energy is the difference in water levels between high tides and low or ebb tides. During one tidal cycle of 12 h and 25 min, the water level rises to maximum during high tides, then it starts falling to a minimum level at low tides and finally it starts rising again to a maximum level at high tides. The difference in water levels between high tides and low tides is the potential energy of water which can be harnessed. This harnessed energy is

called the tidal energy. In a tidal power plant, a reservoir behind an embankment or barrage is filled up during high tides and stored water is made to flow out from the reservoir into sea through turbines coupled to electric generators during low tides. The tidal range can be as high as 15m, but minimum tidal range must be at least 5m for the working of a tidal plant.

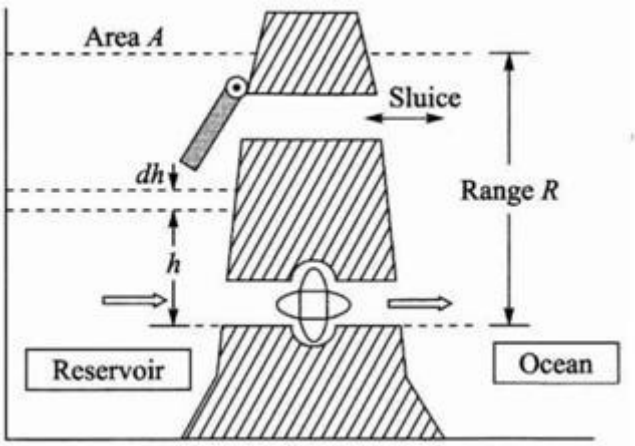


Figure 6.6 Power generation from tidal power plant.

6.3.1 Modes of operation in tidal power plant:

The modes of the operation of a tidal power plant are as follow:

(i) Ebb generation: The reservoir or basin is filled up during high tides. The stored water is made to flow out of the reservoir to ocean through turbines during low tides. The power generation is possible during ebb tides.

(ii) Flood generation: The sea water is made to flow through the turbines into the reservoir or basin during high tides. This process is just reverse of ebb generation. The power generation is possible during high tides.

(iii) Two-way generation: The water is made to flow through turbines for power generation both during high tides from sea to basin and during low tides from basin to sea. The power generation is possible during both low and high tides.

(iv) Pumping and turbining. The reservoir is filled using (i) rise of sea water during high tides and (ii) pumps to pump sea water into the reservoir. The turbine acts as pump to pump water into reservoir during high tides and as a prime mover to the generator during low tides.

6.3.2 **Components of tidal power plant**:

Components of tidal power plant are as follows:

(i) Dam or dyke: The function of a dam or dyke is to form a barrier between the sea and the reservoir/basin. Dam is also built between basins in case the plant has more than one basin.

(ii) Sluiceways: Sluiceways are provided in the dam so that water can enter into basin during high tides. These may also be provided to empty the basin during low tides. Sluiceways are controlled through gates.

(iii) Powerhouse: A powerhouse consists of turbines, electric generators and other auxiliary equipment. The water with high potential energy is made to run through turbines to run generators for power production.

6.3.3 **Feasibility of tidal power plant**:

The feasibility of a tidal power plant depends on the following factors:

(i) Tidal range: The minimum tidal range for economical power production from tidal energy is 5m.

(ii) Cost: The site should be such that it needs a minimum cost to construct a dam to create a basin of a required storage capacity of water in ocean.

(iii) Shipping traffic: The site of the tidal plant should not cause any interruption to the shipping traffic running through estuary.

(iv) Safety: The site of the tidal plant should be well protected, especially from high wave action during storms.

(v) Silt: The silt content in water in estuary at the tidal site should be small to avoid excessive silt deposition in the brain. The silt removal from basin is a costly preposition.

4. **Merits of tidal power plant**:

Merits of tidal energy are as follows:

- It is free from pollution.
- It is inexhaustible.
- The site of the plant can be generally dam at bays and its construction does not uproot the villages or disturb the ecology of the place.
- No submerging of land occurs while constructing basins.
- Its operation is not adversely affected by variations of weather, such as the failure of monsoon. Tide cycle is always definite. Basins can also be used for fish farming.

5. **Limitations of tidal power plant**:

The limitations are as follows:

- It can be harnessed only if natural sites are available.

- Its suitable sites are mostly bays which are far away from the load centers. Therefore, the transmission cost of power is high.
- Its operation is uneven as turbines have to work with varying water heads.
- The power output is variable.
- The construction period of a dam for basin is long. The basin and plant construction is costly.
- Sedimentation and silt deposition in the basin take place in regular manner which is costly to be removed. Power output varies with lunar cycle.
- Supply of power depends on the timing of tides and it is not continuous. Sea water is corrosive. The life of tidal power equipment is affected by the corrosive nature of sea water.
- Efficiency of plant is affected due to variable tidal range.
- More turbines are to be used to obtain sufficient power as water head is small.

4. Classification of tidal power plant.

How tidal plants are classified on the basis of basins used?

The tidal power plants are classified on the basis of basins used as follows:

(i) Single basin system.
(ii) Double basin system.

6.4.1 Single basin system:

Single basin system is the simplest system to generate tidal power. The single basin tidal plant has only one basin to store water. The basin is separated from the ocean/sea by a dam. The turbines and generators are mounted within the ducts inside the dam. The single basin system can be further classified into single ebb cycle system, single tide cycle system and double cycle system.

In single ebb cycle system, the sea water fills up the basin through sluice valves when water level rises in high tides. The stored water in basin is made to run the turbines when the level of sea water decreases during low tides as shown in Figure 6.7(a). The turbines generate power using generators. The power output from this system is intermittent as power can be generated only during low tides.

In single tide cycle system as shown in Figure 6.7(b), the water is made to enter into basin through turbines during high tides. When high tides period is over, the sea level starts falling, which reduces the head on turbines? The power generation is stopped as sea level reduces with the onset of low tides. The basin is drained of water through the sluiceways as sea level is lower during low tides. The power output is, therefore, intermittent.

In double cycle system as shown in Figure 6.7(c), reversible turbines are installed. The power is generated during both filling and emptying of the basin. Filling of basin is done during high tides when water level in basin is low. The water is made to flow through the turbines into basin to run generators. Emptying of basin is done during low tides when sea level is low and level in basin is high. The water is made to flow out of the basin through turbines into sea to run generators. The flow of water is, therefore, used in both directions to drive the reversible turbines. In this system also, continuous power generation is not possible as it takes some time to change from filling to emptying modes of the basin.

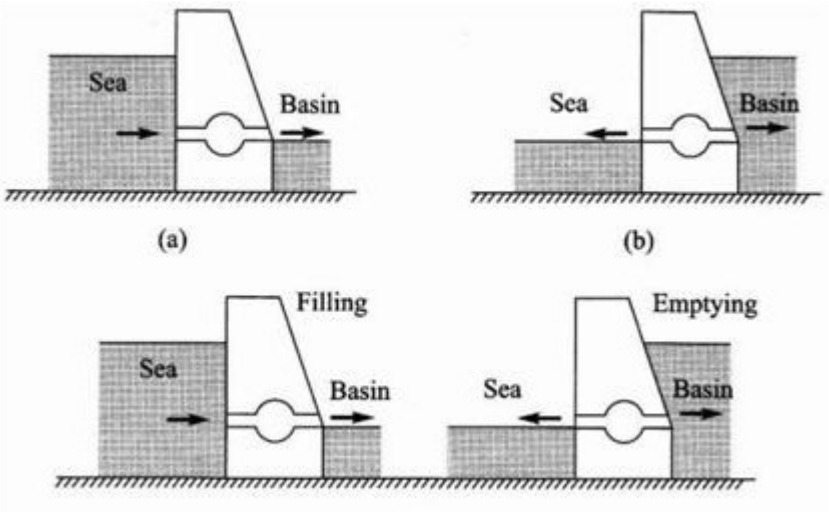


Figure 6.7 single basin arrangements (a) single ebb cycle (b) single tide cycle (c) double cycle.

6.4.2 **Double basin system**:

The double basin power plant has two basins at different levels (Figure 6.8). The dam is provided between basins and sea as well as between basins. One basin is called upper basin as the water level in this basin is always maintained higher than that in the lower basin. The lower basin discharges water to the sea at low tides, while the upper basin is filled up with sea water at high tides. The turbines are provided in the constructed dam separating upper and lower basins. When water is made to flow through turbines from upper basin to lower basin, the turbines run and generators coupled with them generate power.

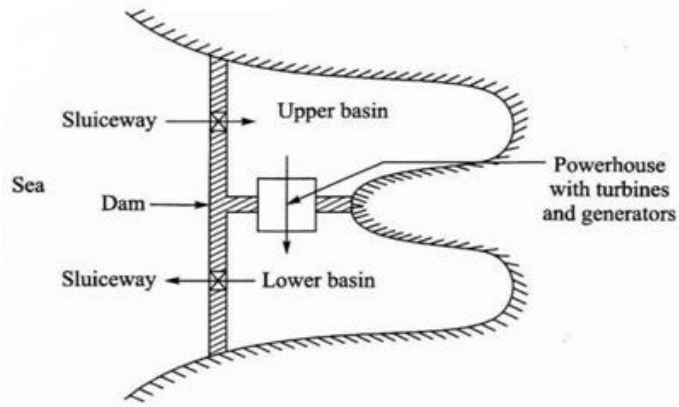


Figure 6.8 Double basin system.

6.5 Site requirements:

requirements are as follows:

- High tidal range.
- Short length of dam to create a basin of reasonable storage. It is possible at a narrow inlet to an estuary or bay.
- Nearer to load location.
- Should be protected from high waves.
- Should not hamper shipping traffic.

6.6 Tidal power plant in India:

The sites suitable for tidal power development in India are as follows:

- Gulf of Kutch (Gujarat)
- Gulf of Khambhat (Gujarat)
- Sundarbans delta (West Bengal) Gulf of Cambay (Gujarat)
- Pitts Creek (West Bengal)

6.7 Working Principle of Ocean Thermal Energy Conversion:

Ocean thermal energy conversion is an indirect method of utilizing solar energy. A large amount of solar energy as thermal energy is collected and stored in tropical oceans. The surface of water acts as the collector of solar heat. The upper water layer in the ocean acts as an infinite heat storage reservoir or a hot temperature source while the deep water layer in ocean acts as a low temperature sink. Solar heat absorption in the ocean water takes place according to Lambert's law of absorption. According to this law, each layer of equal water thickness in ocean absorbs the same fraction of solar heat when solar radiation passes through ocean water. The radiation intensity (I) in waterfalls with depth (y) according to the following relation:

$$\frac{dI}{dy} = \mu I_0$$

where I_0 is the solar radiation intensity at $y = 0$,
μ is the absorption coefficient

On integration, we get

$$I = I_0 e^{-\mu y}.$$

The above relation shows that the radiation intensity falls exponentially with the depth (y). Most of the solar radiation is absorbed very close to the upper surface compared to deep water. Therefore, the maximum temperature exists just below the upper surface due to solar heating and the lowest temperature exists at deep water due to the absence of solar heating. The temperatures are maintained as high at surface and low at deep water as no thermal convection currents between warmer and light water at the top and colder and heavy water at the bottom of the ocean can take place. The warm water stays at the top and cold water stays at the bottom, thereby forming two infinite heat reservoirs of constant temperature, that is, a heat source at the top at about 27°C and a heat sink at about 4°C at some depth from the top. These reservoirs are maintained by the absorption of solar radiation on a regular basis. A heat engine can work between this heat source and heat sink to convert heat into mechanical work. The efficiency of heat engine is limited to Carnot engine efficiency, which is given by

$$\eta = \frac{T_1 - T_2}{T_1}$$

where T_1 is the source temperature in Kelvin and T_2 is the sink temperature in Kelvin.

In case we take T_1 = 27°C and T_2 = 7°C, we have

$$\eta = \frac{(27+273)-(7+273)}{(27+273)}$$

$$= 6.67\%$$

The ocean thermal energy can be converted into mechanical or electrical energy when the temperature difference between the warm water at surface and the cold water at the depths is about 20-25°C. This temperature difference generally exists in tropical oceans. The utilization of this ocean thermal energy

where a suitable temperature difference exists between the warm surface water and the cold water at the depths in tropical oceans by its conversion into mechanical work forms the basis of OTEC system. The warm surface water can also be used to heat some low boiling point refrigerant to obtain high pressure vapors which can run a gas turbine to obtain mechanical work.

6.8 Ocean thermal energy conversion systems:

OTEC plants can operate using open cycle or closed cycle. The open cycle is also known as the Claude cycle while the close cycle is also known as Anderson cycle.

Open cycle:

Warm water from the top surface is evaporated to obtain low pressure steam by using a flash evaporator maintained at partial vacuum as water can evaporate at the lower temperature when pressure is lower than atmospheric pressure. The low pressure steam obtained from flash evaporator is expanded in a turbine to extract mechanical energy. The steam after energy

removal in turbine is condensed into water in a condenser which is cooled by cold water drawn from the depths in the ocean. The working of an open cycle OTEC plant is shown in Figure 6.9.

Closed cycle:

In the closed cycle, warm surface water is used to evaporate a low boiling point refrigerant (ammonia or Freon) and refrigerant vapor is made to flow through the turbine to extract energy. The vapor coming out from the turbine after performing work is cooled and condensed in a condenser cooled by cold water pumped from the ocean depths. The closed cycle is shown in Figure 6.10. Such plant is much compact in size and less costly compared to open cycle OTEC plant.

Figure 6.9 Open cycle OTEC plant.

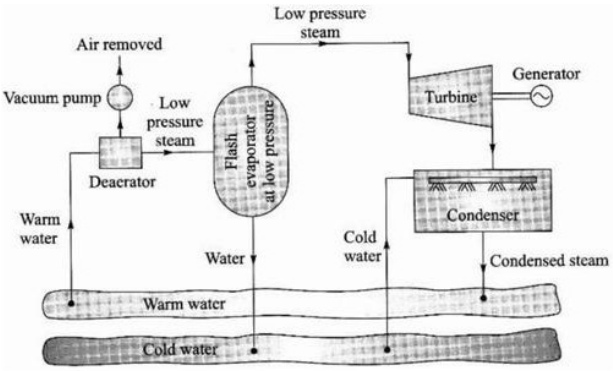
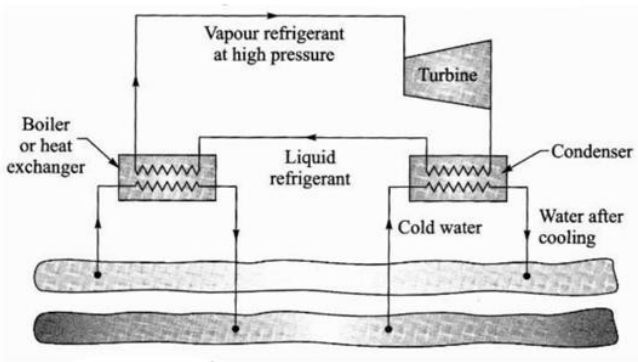


Figure 6.10 Closed cycle OTEC plant.



6.9 Few important OTEC plants installed all over the world:

Many countries are actively involved in research and development of OTEC plants. The plants that have been planned and launched are as follows:

(i) France has built a 5 MW OTEC shore plant in Tahiti.
(ii) A 50 kW floating plant has been built at island of Nauru in Japan. Another 20 MW power plant is to be built by Tokyo Electric Company.
(iii) A 10 MW closed cycle plant in Caribbean or Pacific Ocean and a 500 kW closed cycle onshore plant in Hawaii have been planned by the United Kingdom.
(iv) A 100 kW on shore plant has been completed at Bali. Another 10 MW floating plant is under planning by the Dutch.
(v) A 22 kW OTEC plant at Cuba was built in 1930.
(vi) A 10 MW OTEC plant at Guam has been planned.
(vii) A 1 MW OTEC plant at the Coast of Lakshadweep Island has been planned.

6.10 Merits and demerits of OTEC plant:

The advantages of OTEC are as follow:

(i) The plant can supply steady power without any fluctuation in all the vagaries of weather.
(ii) The power output does not vary from season to season.
(iii) The plant needs usual thermodynamic devices and equipment, such as turbine, heat exchanger and condenser.
(iv) The useful by-products from the OTEC plant are desalinated water and nutrients from marine culture.
(v) The plant can be constructed on shoreline or on floating platform.
(vi) The plant of any size or capacity can be constructed at a suitable site.

The demerits of OTEC plant are as follows:

(i) As low temperature difference exists in upper surface and deep water, thereby plant has a very low efficiency in converting ocean thermal energy. Hence, a large plant size at huge cost has to be constructed to meet the power requirement.
(ii) The design, operation and maintenance of flash evaporator in the open system are problematic.
(iii) The design of steam turbine to operate at low pressure is problematic.
(iv) The large size of heat exchanger to work as boiler is problematic while designing the closed system.
(v) The development of pumps suitable for handling large amounts of water is problematic.
(vi) Long-distance cable to transmit power to shore is required.

(vii) The plant has to withstand severs ocean conditions and storms. The plant equipment has to resist the corrosive effects of ocean water. The plant has to remove algae growth on a regular basis.

(viii) The whole plant has to be constructed on floats. Equipment has to be installed at a great depth to reach the cold water level.

(ix) The plant at shoreline may require pipes of large diameter and length for handling water.

The environmental impacts due to construction of OTEC plant are as follow:

(i) The marine life (eggs, larvae and fish) can be destroyed due to water circulation.

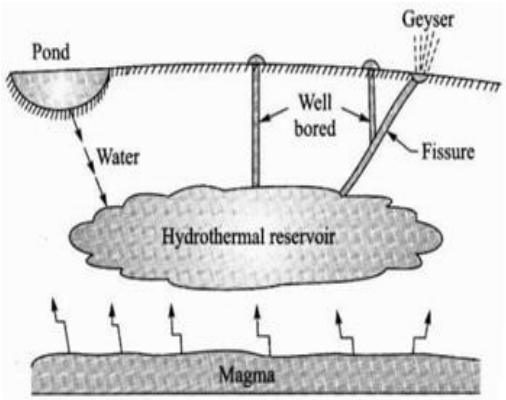
(ii) The plant may affect ecosystem and impact coral. It can also influence ocean currents and climate.

(iii) The plant releases a large quantity of cold water into warmer surface environment which may adversely affect the marine life.

(iv) The carbon dioxide dissolved in warm water is released to the atmosphere in open cycle, which has greenhouse effect on environment.

6.11 Resources of geothermal energy:

The molten mass of the earth is called magma. The earth's crust over the magma is about 32 km on average. However, at certain places owing the earth tremors the magma happens to come closer to earth's surface. This presence of hot magma near to earth's surface creates active volcanoes, hot springs and geysers. It also causes steam to vent through the fissures when underground water comes in contact with magma.



There are five types of geothermal
resources, which include hydrothermal, geopressured, hot dry rock, active volcanic vents and magma.

Hydrothermal resources contain superheated water, steam or both in fractured or porous rock, but further trapped by a layer of impermeable rock. Hydrothermal resource may give dry and

pure steam with temperature above 240°C. However, majority of these resources have moderate temperatures ranging from 100 to l80°C, while few resources

have high temperatures ranging from 150 to 200°C. To use hydrothermal energy, wells have to be drilled to reach a fissure or hydrothermal reservoir as shown in Figure 6.11.

Geopressured resource is hot water or brine trapped underground at the depth of about 2400-9100 m with temperature at about l 60°C. The pressure of the water is about 1000 bar. Although it has great heat potential for power

generation but it is uneconomical due to low temperature and high cost of drilling into earth's surface to such a great depth. In case brine has recoverable

methane, brine water can be used with combustion of methane to generate electricity.

Hot dry rocks or petro thermal resources consist of high-temperature rocks ranging from 90 to 650°C. The rocks can be fractured and water may be circulated through the rocks to extract thermal energy.

Geothermal energy in the form of active volcanic vents occurs in many parts of the world. There is molten rock or magma present in these volcanic vents at temperature ranging from 700 to l 600°C. Magma chambers have got huge thermal energy compared to other geothermal resources. However, extracting thermal energy from volcanic vents is difficult.

Molten rock or magma may be present at shallow depths at certain places. The heat can be easily extracted at these places.

As we travel down earth's surface radially, there exists a temperature gradient of 0.03°C per meter. Thus a 30°C increase in temperature can be obtained per kilometer depth from the earth crust.

6.12 Structure of earth's interior:

The earth consists of the following parts of (concentric shells)

(i) ***CRUST***: It is the uppermost shell of earth that extends to variable depths below mountains, continents and oceans. The thickness of crust is believed to be 0.90 km and several substances like limestone, coal, gold, petroleum etc. are found in the crust.

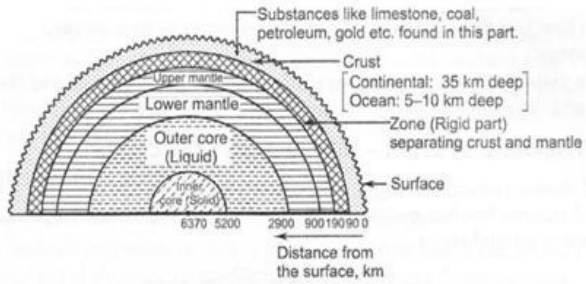
(ii) ***MANTLE***: It is the second concentric shell of earth that lies below the crust. The upper rigid part of the mantle extends up to 100 km below the separating crust and contains mainly iron and magnesium. The

crust and upper mantle form the 'lithosphere'. The lower mantle extending up to 2900 km below the earth's surface is less rigid and is hotter. This is known as 'asihenosphere' and is capable of being

deformed. The movement of lithosphere over the asthenosphere results in the 'phenomenon of plate tectonics' i.e. Movement of the earth's crust.

(iii) ***CORE***: It is the innermost concentric shell of the earth. The core boundary begins at a depth of 2900 km from the surface and extends to the centre of the earth at 6370 km.

This layer is further subdivided into outer core and inner core. The outer core comprises the region from a depth of 2900 km to 5200 km below the earth's surface and behaves mere like a liquid. The inner core with a thickness of around 1170 km is believed to be a solid metallic body, containing nickel-iron alloy. The hot molten rock



of the mantle is called .
Magma

Figure structure of earth's interior

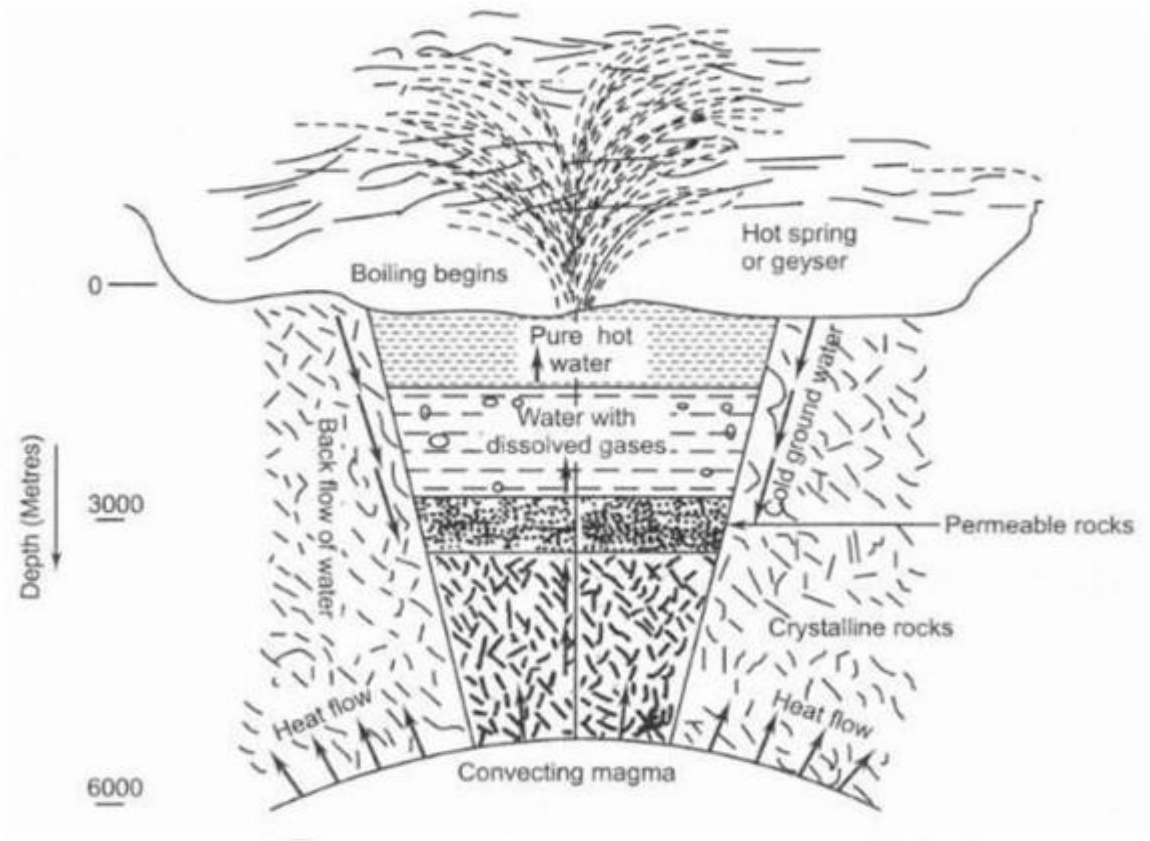


Fig. 6.13 shows a schematic diagram depicting how hot springs (geysers) are produced through hot magma (molten mass), the fractured crystalline rocks, the permeable rocks and percolating ground water.

At a depth of 5000m or so lies an impermeable magma. Above the magma are the 'impermeable rocks' which are overlain by localized pockets of 'permeable rocks'. One such localized pocket is shown in this figure. The localized pockets are bounded by fracture zones or faults along which some

relative motion of rocks has occurred. Water circulates along the fault lines. As it goes down and moves in earth's interior it is heated by the permeable layer

which is in turn heated by conduction of heat from the magma. The hot water comes out through another fault and forms a hot spring.

13. Geothermal power plants:

1. Hydrothermal resources:

Hydrothermal resources are formed when underground water has access to high-temperature, porous rocks, capped by a layer of solid impervious rock. The entrapped water is heated by surrounding rocks. The hydrothermal resources can be classified depending on the heating of entrapped water as dry steam fields or vapor dominated resources, wet steam fields or liquid dominated resource and hot water resource. Vapor dominated fields can deliver steam with almost no water. Liquid dominated fields can deliver the mixture of steam and hot water, while hot water resource can only deliver hot water.

Vapor dominated plant

Water boils underground in a hydrothermal resource when it has pressure of about 7 atm and temperature of about 165°C. The dry steam fields are located at the Geysers region of California (USA), the Larderello (Italy) and the Matsukawa region of Japan. The plant consists of

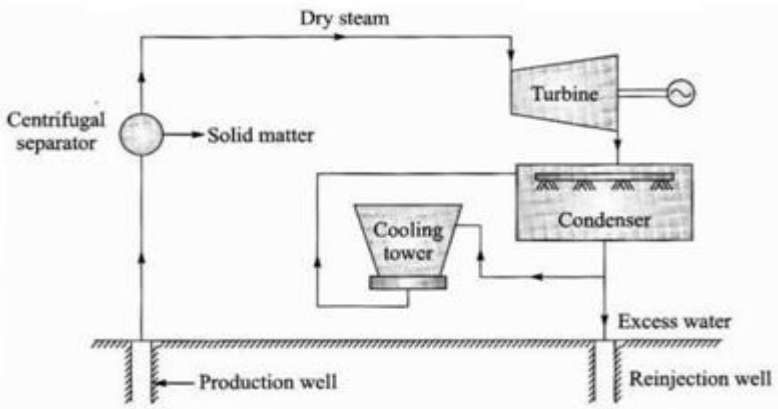


Figure 6.14 Dry steam hydrothermal plants.

(i) Production well to extract steam from the hydrothermal resource.

(ii) A centrifuge separator to remove solid matter from the steam.

(iii) A turbine to convert thermal energy into mechanical energy.

(iv) A generator coupled to turbine to generate electric power.

(v) A condenser to condense wet steam exited from turbine into water by direct contact with cooling water.

(vi) A cooling tower to cool warm water exited from the condenser and returning the cooled water to the condenser.

The excess water is disposed of in the reinjection well as shown in Figure 6.14. The cycle used in this system is called Rankine cycle.

Wet steam or liquid dominated

The wet steam or liquid dominated fields or resources can be further divided into high temperature (above l 75°C) enabling the use of flash steam evaporator to produce dry steam and low temperature (range of 95-l75°C) where geothermal heat is used to vaporize a violatic refrigerant.

(i) **Liquid dominated high-temperature plant or system**. The type of plant or system is used where hydrothermal reservoir has temperature and pressure of 230°C and 40 atm respectively. The plant consists of flash evaporator to obtain dry steam from high temperature wet steam by lowering pressure in it, turbine with directly coupled generator to extract energy from dry steam, condenser to condense used steam into water and cooling tower to cool the warm water. The excess water is disposed of in the ground as shown in Figure 6.15. In dual flash system, the hot water is flashed in two flash evaporators in two stages. Steam obtained in the first stage is used in low pressure turbine and steam is again flashed to obtain high pressure to be used in high pressure turbine as shown in Figure 6.16. The 50 MW Hatchobane plant, Kyushu in Japan is a double flash system.

(ii) **Liquid dominated low-temperature plant or system**. The water available from the hydrothermal reservoir is at low temperature range of 90-l75°C, which is insufficient to produce steam using a flash evaporator. A low boiling point refrigerant is used as a working medium. The plant runs on binary cycle. The refrigerant is evaporated in a heat exchanger using the heat of water obtained from hydrothermal reservoir. The refrigerant vapor runs the turbine with a generator coupled to it. The used refrigerant vapor is condensed in a condenser. The cooled water for cooling in condenser is obtained from a cooling tower. The binary cycle system is shown in Figure 6.17. Kamchatka binary cycle plant in Russia is a 680 kW capacity plant using hot hydrothermal water at 80°C. The working fluid is Freon-12.

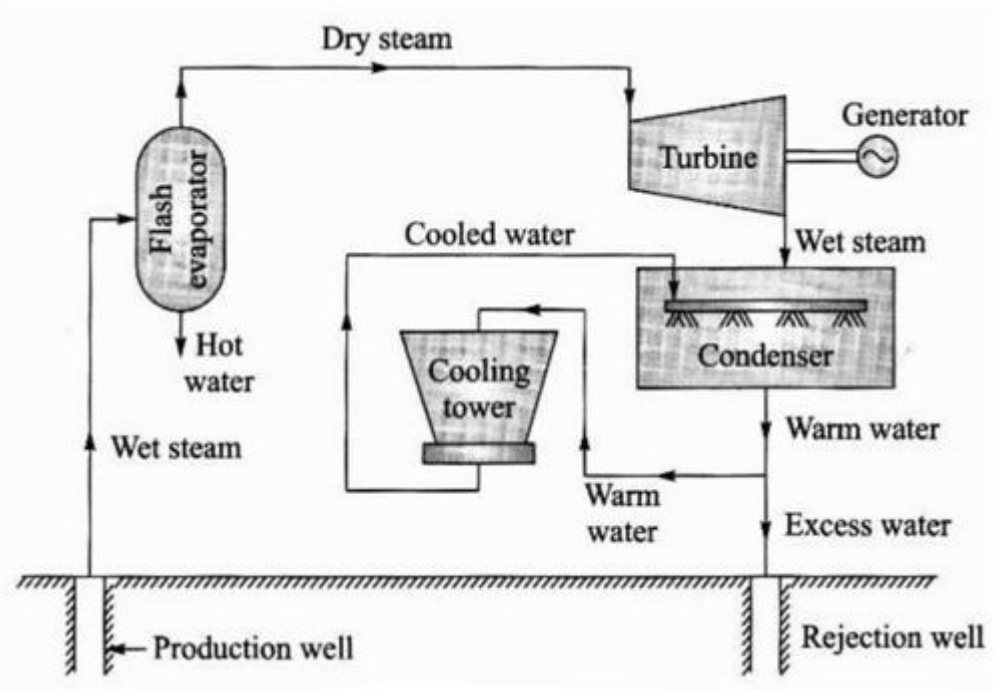


Figure 6.15 Single flash system in liquid dominated high-temperature plant.

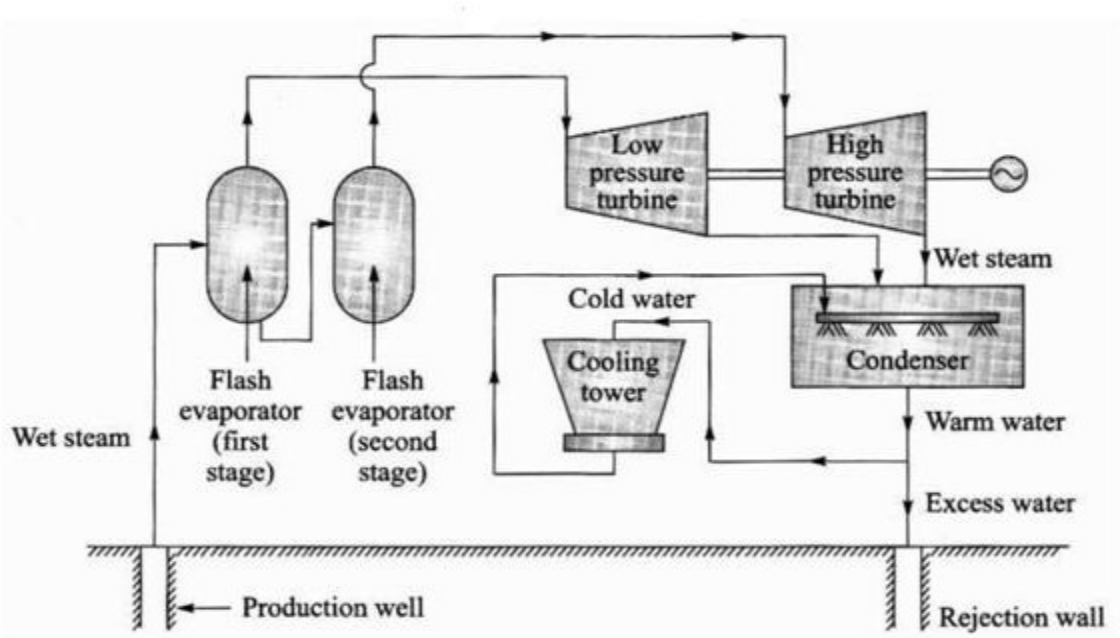


Figure 6.16 Double flash system in liquid dominated low-temperature plant.

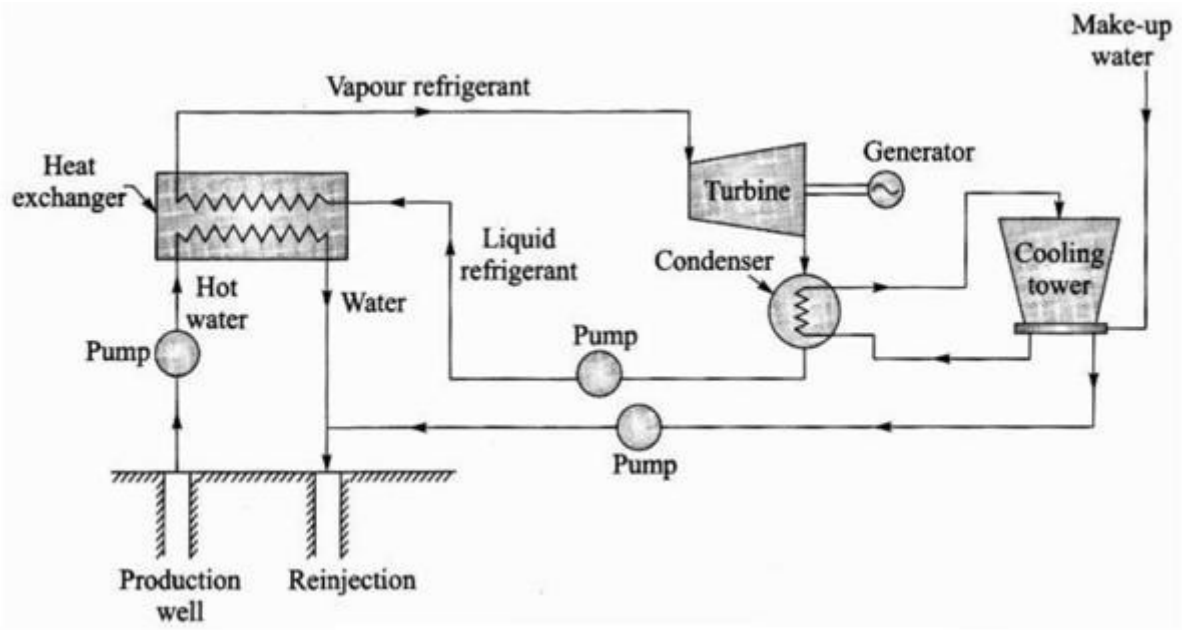


Figure 6.17 Binary fluid hydrothermal system (low temperature)

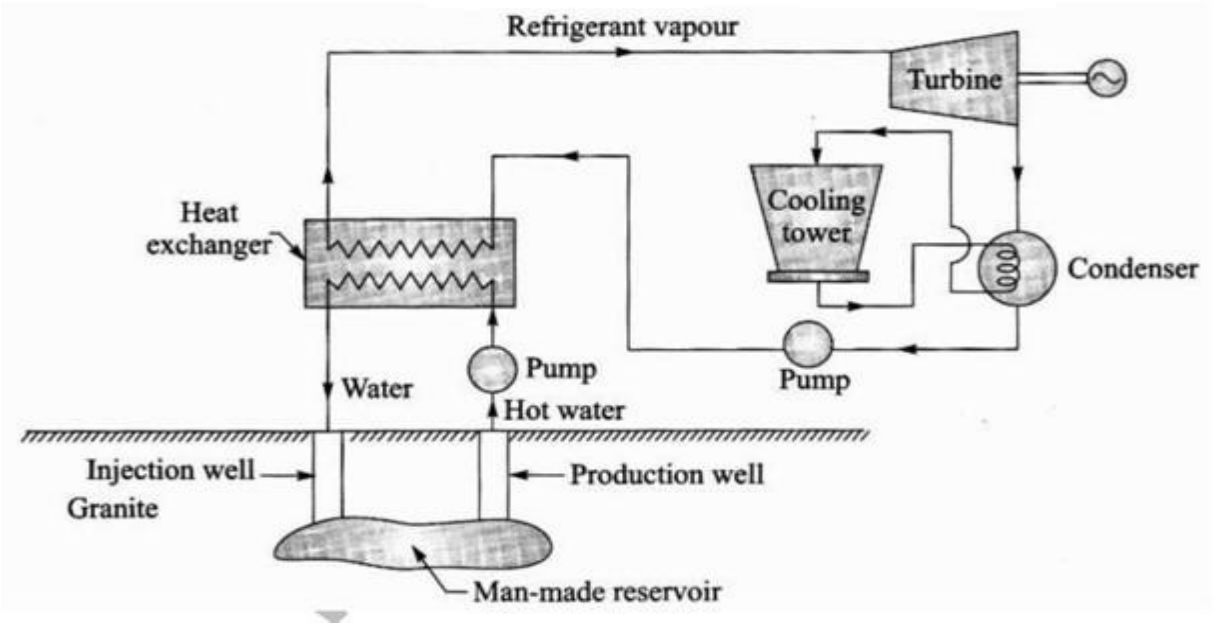


Figure 6.18 High dry rock binary fluid system.

6.13.2 <u>Hot dry rock resources</u>:

Hot dry rocks (HDR) resources or dry geothermal fields are much more common than hydrothermal reservoirs. The working of high dry rock binary fluid system is shown in Figure 6.18. These HDR resources are more accessible

compared to hydrothermal resources. The underground hot dry rocks due to geothermal heating have temperatures exceeding 200°C and there is no water in their vicinity. Water as heat transfer

fluid has to be injected into a man-made reservoir in the hot dry rocks field. After drilling and fracturing of the field, a man-made reservoir is created.

Injection for wells pumping inside and production or extraction wells for hot water pumping out are drilled. A series of injection wells and extraction wells can be drilled to tap a sufficient amount of geothermal energy. The hot water extracted from the man-made reservoir is made to vaporize low boiling point refrigerant which is used to run a turbine coupled with a generator. The refrigerant vapor exiting the turbine is condensed in a condenser which is pumped into the heat exchanger again. The viability of extracting energy from a dry field depends upon the degree to which the resource field can be fractured to develop man-made geothermal reservoir.

6.13.3 **Comparison of geothermal power plant with conventional thermal power plant:**

The main differences between the geothermal power plant and the conventional thermal power plant are as follow:

(i) The temperature and pressure in the geothermal power plant are less (about l 70°C and 8 atm) compared to those in the conventional thermal plant (temperature about 540°C and pressure about 160 atm). The efficiency of geothermal plant is about 15% while it is about 40% in case of the conventional thermal plant.

(ii) The size of a geothermal power plant· depends on the amount of geothermal energy available. The size of a geothermal plant is generally small on account of smaller thermal potential of the site.

(iii) Geothermal power plant needs a larger flow of geothermal fluid due to lesser temperature and pressure compared to conventional power plant.

(iv) Geothermal power plant has to be located where geothermal fields exist. It is technically infeasible to transport geothermal energy over long distance. The transmission cost of power for geothermal power plant is more.

(v) Hydrothermal plant does not need water for cooling purpose unlike conventional power plant.

(vi) Hydrothermal plant causes lesser pollution compared to conventional power plant.

(vii) Hydrothermal plant does not need any supply of fuel.

6.13.4 **Advantages and disadvantages of geothermal energy:**

The main advantages of geothermal energy are as follows:

(i) It is a reliable source of energy.

(ii) It is in continuous supply.

(iii) Its availability is independent of weather.

(iv) It has an inherent storage capability and it does not require any storage device.

(v) Small space is required to install the plant.

(vi) It does not require any supply of fuel to generate heat.

(vii) It is the least polluting.

(viii) It is versatile in use.
(ix) It is cheaper than other energy sources.

The major disadvantages of geothermal energy are as follows:

(i) Geothermal energy is available as low-grade heat, that is, temperature of geothermal fluid is low.
(ii) Geothermal fluids also bring dissolved gases and solute, which lead to air and land pollution.
(iii) Removal of heated water from the hydrothermal reservoir may lead to land subsidence or seismic imbalance.
(iv) Drilling and blasting of wells may cause instability of land structure and may develop risk of any earthquake or seismic imbalance.
(v) Geothermal energy cannot be transported over long distances (less than 30 km).
(vi) The life of plant equipment is limited due to corrosive and abrasive nature of geothermal fluids.

6.13.5 **Criteria for selection of geothermal site:**

The criteria for selecting a site for geothermal power generation are as follow:

(i) Vapor dominated geothermal site is preferred as it is possible to obtain dry steam at about 200°C and pressure of 8 atm.
(ii) Site should facilitate easy drilling to reach geothermal energy resource with least cost.
(iii) Site should have sufficient geothermal energy to run a plant of adequate power capacity.
(iv) Site should be near the load centre to reduce the cost of transmission.
(v) The dissolved gases and solids in the geothermal fluids should be as little as possible.

6.13.6 **Potential sites for geothermal energy in India:**

potential sites in India are as follows:

The Himalayas (Puga valleys, Manikaran) Sohana
West coast (Unai)
Cambay (Tuwa)
Son-Narmada-Tapi (SONATA)
Godavari Mahanadi

Part B

Unit – VII:

Energy from Bio-mass: *Photosynthesis, photosynthetic oxygen production, energy plantation, bio-gas production from organic wastes by anaerobic fermentation, description of bio-gas plants, transportation of bio-gas, problems involved in bio-gas production, application of bio-gas, application of biogas in engines, advantages.*

1. Introduction:

Plants grow through photosynthesis process which takes place primarily in their green leaves. Biomass is mainly in the form of wood and it is the source of energy. Biomass is used both in domestic and in industrial activities by way of direct combustion. Hence, we use solar energy in the form of biomass for cooking and heating purpose. The dominant use of biomass or fuel wood in the world is made for cooking and heating primarily in rural areas. Biomass accounts for about 15% of the energy used in the world. Biogas is the gaseous fuel which is obtained from biomass by means of anaerobic fermentation. The raw materials for biogas include waste from agriculture, waste from forest, rural animal waste, urban waste (left over food and other rubbish) and aqua waste (fishery, algae and hyacinth).

2. BIOMASS:

What is biomass? In what form, biomass can be used?

Biomass is organic or carbon-based material that can either react with oxygen for combustion or undergo metabolic process to release heat. Biomass can be used as such in its original form. More often, it is transformed to more convenient and useful form, thereby forming solid, liquid and gaseous fuels.

1. Biofuels:

What are the different forms of biomass available as bio-fuels?

The bio-fuels can be fuel wood, charcoal, fuel pellets, bio-ethanol, biogas, producer gas and biodiesel.

Fuel wood: It is the most common source of biomass energy. Direct combustion is the simplest way to obtain heat energy. It has energy density of about 16-20 MJ/kg

Charcoal: It is obtained by carbonization of woody biomass. This helps in providing higher energy density per unit mass of about 30 MJ/kg. Charcoal can burn without generating smoke.

Fuel Pallets: Fuel pellets are formed from crop residues such as straw or rice husk which are pressed into solid mass.

Bio-ethanol: It is derived from wet biomass containing sugars from sugarcane, starches from grains and potatoes or cellulose from woody matters. Ethanol (C_2H_5OH) is a colorless liquid bio-fuel with boiling point of 78°C and energy density of 26.9 MJ/kg.

Bio-gas: Biogas is the gaseous fuel obtained from biomass (organic waste from plants, animals and humans) by means of anaerobic digestion or fermentation. The anaerobic digestion process can be profitably applied to any wet organic matters. Anaerobes are microorganisms or bacteria found to live and grow in organic matter at the temperature of less than 60°C in presence of moisture but in the absence of air or oxygen. The anaerobic organism consumes oxygen which it obtains from decomposition of organic matters. Decomposition of the organic matters by anaerobic micro organism is called digestion or fermentation. The biogas is liberated from the organic matters during digestion or fermentation. The biogas produced by digestion contains (i) methane gas (CH_4) 65-75%, (ii) carbon dioxide gas ($C0_2$) 25-35% and (iii) small traces of nitrogen, ammonia, hydrogen sulphide and other gases. The biogas has energy density of about 23 MJ/m^3. It can be used for cooking, lighting, heating and operating small IC engines.

Producer gas: It is obtained by gasification of solid fuels. In this, woody matter (crop residue, wood chips, rice husk, coconut shell and sugar cane residue) is converted into producer gas by thermo chemical method which is in fact the partial combustion and reduction operation of biomass. The producer gas has 19% carbon monoxide, 18% hydrogen, 1% methane, 11% carbon dioxide and the rest remaining nitrogen. The producer gas is used for IC engines for running pumps, motor vehicles, heating and generation of steam in a small-scale power plant.

Biodiesel: It is produced by blending of vegetable oils, with normal diesel to obtain cheaper version of diesel engine fuel. Besides vegetable oils, certain hydrocarbons having molecular weight equal to that of petroleum and that are obtainable as by-products from certain plants can also be used for blending purpose.

7.2.2 *Biomass resources*

What are the biomass resources for the production of biomass energy?

The biomass resources include organic materials obtainable from forest, agriculture, aqua culture and organic waste residue from industrial and social activities.

(i) Forests: Forests (natural or cultivated) are source of fuel wood, charcoal and producer gas. Forest waste and residues from forest processing plants can be used as biomass. Certain plants produce seeds to yield vegetable oils which can also be used in bio-fuels.

(ii) Agricultural residue: Straw, rice husk, groundnut shell, coconut shell and sugarcane bagasse is crop residues which are the main biomass resources. The crop residues are generally gasified to obtain producer gas. The crop residues are also converted into fuel pellets to be used as solid fuels.

(iii) Energy Crops: Energy crops are those cultivations which provide raw materials for bio-fuels. These include (i) sugar plants to provide bio-ethanol, (ii) starch plants (tubular plants and grains) to produce bio-ethanol and (iii) oil producing plants (sunflower, palm oil, groundnut and cottonseeds) to produce biodiesel.

(iv) Urban waste: Urban waste can be garbage or municipal solid waste (MSW) and sewage or liquid waste. Garbage can be burnt to obtain biomass energy while sewage has to be processed to obtain biogas.

(v) Aquatic plants: Certain aquatic or water plants are capable of growing extremely fast and supply organic raw materials for producing biogas. The fast growing water plants include water hyacinth, seaweed, algae and kelp.

The biomass sources are highly dispersed and bulky and contain large amount of water (50 to 90%). Thus, it is not economical to transport them over long distances, and as such conversion *into usable Energy must take place close to the source, which* is *limited to particular regions. However, biomass can be converted to liquid or gaseous fuels, thereby increasing its energy density and making transportation feasible over long distances.*

7.2.3 *Availability of biomass:*

Write a short note on availability of biomass.

The total terrestrial crop alone is about $2X10^{12}$ metric tons. This includes: (i) Sugar crops such as sugarcane and sweet sorghum; (ii) Herbaceous crops, which are non-woody plants that are easily converted into liquid or gaseous fuels; and (iii) Silviculture (forestry) plants such as cultured hybrid poplar, sycamore, sweatgum, alder, eucalyptus and other hardwoods.

The terrestrial crops have energy potential of $3X10^{22}$ joules. The efficiency of solar energy utilization in natural photosynthesis is only 0.1to 2 percent. At present only 1 percent of world biomass is used for energy conversion. Current *research* focuses on the screening and identification of species that are suitable for short-rotation growing and on optimum techniques for planting, fertilization, harvesting and conversion. Fast growing trees, sugar, starch and oil containing plants can be cultivated which have about 5 percent efficiency of solar energy utilization. The estimated production of agricultural residue in India is 200 million tonnes per year and that of wood is 130 million tonnes.
Aquatic crops are grown in fresh sea and brackish waters, both submerged and emergent plants. These include seaweeds, marine algae etc.

Animal and human wastes are an *indirect terrestrial crop* from which methane for combustion, and ethylene can be produced while retaining *the fertilizer value of the manure. The daily produce of cow dung is about 13.5 kg per cattle which can be used to produce 0.46m^3 of biogas in* ***'Gobar gas*** *plant'. This gas is sufficient to produce 1 kWh of electricity in a biogas engine.*

The human waste can also be used for production of biogas. Community latrines can be planned in the villages for collection of night soil for feeding to biogas plants. Wastes of 200 persons can be used to produce about 5m^3 of gas per day to extract 12 kWh of equivalent energy by running a biogas engine.

7.2.4 *Advantages and disadvantages of biomass energy*

What are the *Advantages and disadvantages of biomass energy*

Advantages

It is a renewable source.

It can be stored and used as per the requirement. It helps in waste management.
It is an indigenous source of energy.
It helps in economic development of rural areas.

It helps in improving sanitation in rural areas and towns. It helps in providing fertilizers.
It provides economical use of various types of wastes and residues.

Disadvantages

It has low energy density.
It is a labor intensive energy source.

Its production requires large land area.

Relatively expensive energy consumption.

Low conversion efficiency (i.e. small percentage of sunlight is converted to biomass by plants).

Relatively low concentration of biomass per unit area of land and water.

7.2.5 *Environmental effects of biomass/biofuels*

List out few Environmental effects of biomass/biofuels

Biomass can pollute air when it is burned but less than those of fossil fuels.

Biomass, when burned, does not release green-house gases (or CO_2).

Burning biofuels do not produce pollutants like sulphur that results in acid rain.

When biomass crops are grown, nearly equivalent amount of CO_2 is captured through photosynthesis.

3. Photosynthesis

Explain the process of Photosynthesis. What are the conditions necessary for it?

The preparation of food by the leaves of green plant and micro-organism in presence of sunlight, chlorophyll, water and "CO_2" is called photosynthesis.

In this process, the CO_2 from the atmosphere combines with water and light energy to produce carbohydrates (i.e., sugars, starches etc.) and oxygen.

The photosynthesis process can be represented by the following reaction

$$6CO_2+6H_2O+\text{light energy} \rightarrow C_6H_{12}O_6+6CO_2$$

Biomass does not add CO_2 to the atmosphere as it absorbs the same amount of carbon in growing the plants as it is released when consumed as fuel. It is a superior fuel as the energy produced by biomass is **'carbon cycle neutral'**.

The conditions necessary for photosynthesis are

(i) Light: The intensity of solar radiation of 400-700 A wavelength is one of the important inputs for biomass production, this range of light is called 'photo synthetically active radiation (PAR)'. The upper limit of photosynthesis efficiency is about 5 percent.

(ii) CO_2 concentration: CO_2 is primary raw material for photosynthesis. The main sources of CO_2 are:

Animal respiration, Combustion of fuel, Decay of organic matter by bacteria, Ocean (respiration of marine plants and animal releases CO_2 into the water)

(iii) Temperature: The process of photosynthesis is restricted to temperature range of 0 to 60 ^oC which can be tolerated by proteins.

The energy stored in the plants by way of carbon fixation in the form of chemical bond energy when expressed as a fraction of total insolation falling on the plant, is called as photosynthetic efficiency.

4. BIOGAS

What is biogas?

Biogas is the gaseous fuel which is obtained from biomass by means of an anaerobic digestion or fermentation of wet organic matters. The biogas is a flammable gas. The composition of biogas includes 50-60% methane gas, 35-40% carbon dioxide, 5% hydrogen and a small amount of hydrogen sulphide and other gases. Methane and hydrogen gases form the combustible portion of biogas. The biogas has energy density of about 23 MJ/m^3. It can be used for cooking's, heating, lighting and running small IC engine.

1. Biomass conversion process

List and explain the biomass conversion process.

The following processes are used for the biomass conversion to energy or to biofuels:

(i) **Densification:** In this process bulky biomass is *reduced to a better volume-to-weight ratio by compressing in a die at a high temperature and pressure.* The biomass pressed into briquettes or pellets (easier to transport and store) can be *used* as clean fuel in *domestic chulhas, bakeries and hotels.*

(ii) **Combustion and incineration:**

Combustion:

Combustion is the process of burning in presence of oxygen to produce heat (utilized for cooking, space heating, industrial purposes and for electricity generation), light and by products.

The combustion of biomass is more difficult than other fuels since it contains relatively higher moisture content. Biomass is free from toxic metals and its ash.

This method is very inefficient with heat losses to 30 to 90% of the original energy contained in the biomass.

The technology of *"fluidized bed combustion"* may be used for the efficient combustion of forestry and agricultural waste material such as sawdust, wood chips, hog fuel, rice husks, straws, nutshells and chips.

In fluidized bed combustion of *biomass, the biomass is fed into a bed of hot inert particles,* such as sand kept in fluidized state with air at sufficient velocity from below.

The operating temperature is normally controlled within the range 750 – 950 C, ideally it is kept as high as possible in order to maximize the rate of combustion and heat transfer but low enough to avoid the problem of sintering of the bed particles. The rapid mixing and turbulence within the fluidized bed enables efficient combustion to be achieved with high heat releases, as well as effective transfer, than in a conventional boiler. This can result in more compact boiler with less number of tubes.

Incineration: It is the process of burning completely the solid asses to 'ashes' by high temperature oxidation. Although the terms combustion and incineration are synonymous, yet the combustion process is applicable to all fuels (i.e. solid, liquids and gases). Incineration is a special process which is used for incinerating municipal solid waste to reduce the volume of solid refuse (90 percent) and to produce heat steam and electricity.

Pyrolysis: Wood, dung, vegetable waste can be dried and burnt to provide heat or converted into low calorific value by pyrolysis. In the pyrolysis process, the organic material is converted to gases, solids and liquids by heating 500 to 900 C in the absence of oxygen.

Thermo-chemical conversion

It is process of decompose biomass with various combinations of temperature and pressures.

Thermo-chemical conversion takes the following two reasons

Gasification: It is the process of heating the biomass with limited oxygen to produce 'low heating value' or by reacting with with steam and oxygen at high pressure and temperature to produce 'medium heating value gases'.

The output gas is known as "producer gas", a mixture of H_2 (15-20%), CO (10-20%), CH_4 (1-5%), CO_2 (9-12%) and N_2 (45-55%). As compared to solid mass the gas is more versatile; it can be burnt to produce heat and steam, or used in I.C. engines or gas turbines to generate electricity.

Liquefaction: Biomass can be liquefied through fast or flash pyrolysis, called "pyrolytic oil" which is dark brown liquid of low viscosity and a mixture of hydrocarbons.

Biomass can also be liquefied by "methanol synthesis". Gasification of biomass produces synthetic gas containing a mixture of H_2 and CO. the gas is purified by adjusting the composition of H_2 and CO. Finally; the purified gas is subjected to liquefaction process, converted to methanol over zinc, chromium catalyst.Methanol can be used as liquid fuel.

(iv) Biochemical conversion

In biochemical conversion there are two principal conversion processes:

***Anaerobic digestion*:** This process involves 'microbial digestion' of biomass and is done in the absence of oxygen.

The process and end products depend upon the micro-organisms cultivated under culture conditions. (an anaerobe is a microscopic organism that can live and grow without external oxygen or air: it extracts oxygen by decomposing the biomass at low temperatures up to 65 C, in presence of moisture).

This process generates mostly methane (CH_4) and CO_2 gas with small impurities such as hydrogen sulphide.

The output gas obtained from anaerobic digestion can be directly burnt, or upgraded to superior fuel gas (methane) by removal of CO_2 and other impurities. The residue may consist of protein-rich sludge and liquid effluents which can be used as animal feed or for soil treatment after certain processing.

***Aerobic decomposition*:** is done in the presence of oxygen and it produces CO_2, NH_3 and some other gases in small quantities and large quantity of heat. The final by-product of this process can be used as fertilizer.

Fermentation: is the process of decomposition of organic matter by micro-organisms especially bacteria and yeasts. It is well established and widely used technology for the conversion of grains and sugar crops into ethanol (ethyl alcohol). Ethanol can be blended with gasoline (petrol) to produce gasohol (90% petrol and 10% ethanol). Processes have been developed to produce various fuels from various types of fermentations.

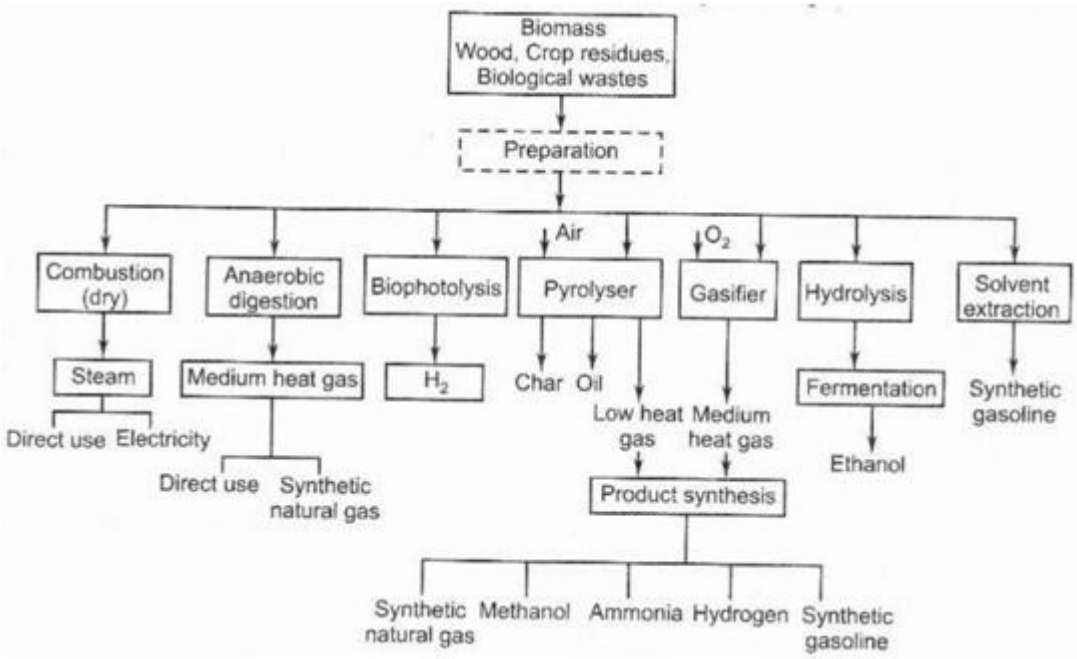


Figure 7.1 Biomass conversion technologies and products

7.4.2 *Anaerobic Digestion*

Explain anaerobic digestion.
Draw the schematic diagram of anaerobic digestion showing input materials and effluents.
Write the basic chemical reaction, process and energetic involved in generation of biogas from biomass.
Explain the process of production of biogas from biomass. What are the main advantages of anaerobic digestion of biomass.
What are the factors affecting the performance of biogas digester?
What are the raw materials can be used for the production of biogas? How biomass conversion takes place?

Biogas is produced from biomass slurry having 90-95% water content by the bacterial action of microorganism called anaerobe. The carbon part of biomass is oxidized and the remaining is reduced to produce mainly methane gas (65-75%) and carbon dioxide (25-35%). These bacteria are found to live and grow without atmospheric oxygen as they produce themselves the needed oxygen by decomposing the biomass. The digestion or fermentation process of wet biomass by these bacteria is favored by the factors such as wetness, warmness and darkness conditions.

Anaerobic digestion system consists of the following three stages.

(i) Hydrolysis or organic matter
(ii) Acidification
(iii) Methane formation

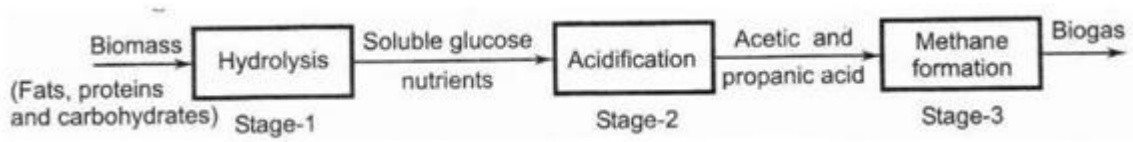


Figure 7.2 Anaerobic digestion

Hydrolysis or organic matter: In this stage, the complex compounds, such as fats, proteins and carbohydrates are broken into small size compounds **through the effluence of water and enzymes called 'hydrolysis'**

Reaction of hydrolysis

$$\underbrace{(C_6H_{10}O_5)n + nH_2O}_{\text{Cellulose + Nutrients}} \xrightarrow{\text{Enzymes}} \underbrace{n(C_6H_{12}O_6)}_{\text{Soluble glucose + Nutrients}}$$

Acidification: In this stage, the soluble glucose and nutrients are converted into simpler volatile fatty acid and acetic acid as byproduct, which accounts for 70% of methane byproduct with the help of acid forming bacteria.

Reaction of acidification:

$$C_6H_{12}O_6 \xrightarrow[\text{bacteria}]{\text{Acid producing}} 2CH_3CH_2OH \text{ (Ethylalcohol)} + 2CO_2 + \text{Fatty acid} + H_2 + \text{other products}$$

Methane formation: During this stage, the methane producing bacteria converts **the organic acids into biogas having its main constituent as 'metahne'.**

Reactions of methane formation

$$2CH_3CH_2OH + CO_2 \xrightarrow[\text{bacteria}]{\text{Methane producing}} 2CH_3COOH + CH_4$$

$$CH_3COOH \longrightarrow \underbrace{CH_4}_{\text{Methane}} + CO_2$$

Digester: The anaerobic digester or plant is shown in Figure 7.3 Feed consists of organic material slurry prepared in mixing tank. Feed supply per day to the digester is called the loading rate. Neither overloading nor under loading of the digester is desirable as it reduces biogas production. The acid forming bacteria grows rapidly, whereas methane forming bacteria (anaerobe) grows slowly. To

obtain maximum biogas generation rate, seeding of digestion slurry with methane forming bacteria is done. This is achieved by adding certain portion of digested slurry to the fresh slurry. It is also possible to add nutrients containing nitrogen, hydrogen, oxygen, phosphorous, sulphur and carbon, which can also increase the anaerobic digestion rate. The recommended pH value for the digestion of biomass slurry is about to 7-8.

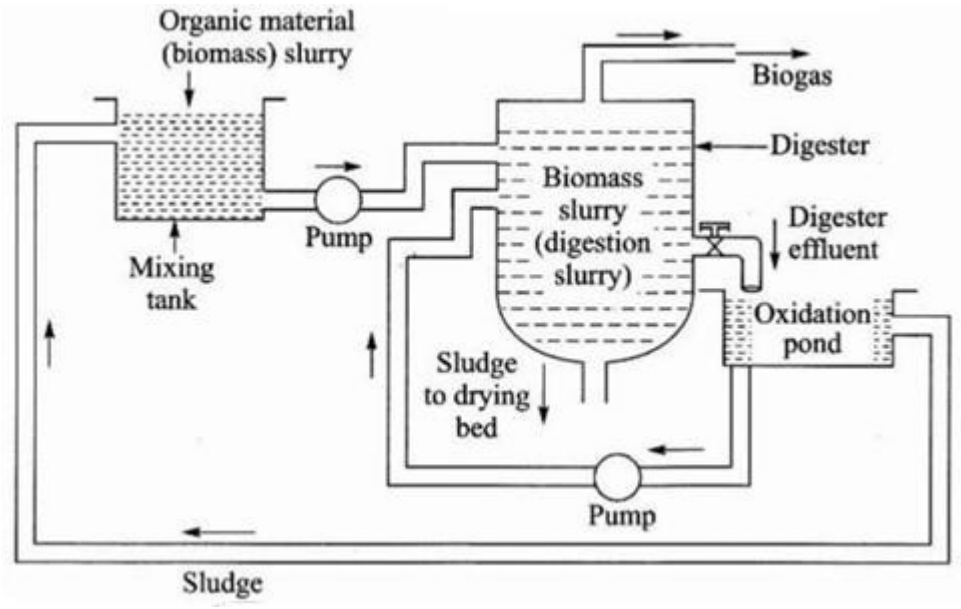


Figure 7.3 Biogas digester or plant

Advantages of anaerobic digestion

It helps to obtain energy from discarded or waste matter. Otherwise, waste matter has to be disposed off with some additional cost.

It helps to provide two main benefits which include fuel by biogas and fertilizer in the form of sludge.

The process helps in conserving complete nitrogen content of the biomass. Hence, fertilizer produced as sludge is better in terms of both quantity and quality.

It helps in the waste management of an industry such as dairy or milk processing plant with simultaneously meeting the energy requirement of the same industry.

It helps in the urban waste management such as municipal solid waste or garbage and sewage or liquid waste. The better management of urban waste improves the sanitation and hygiene in villages and towns.

Anaerobic digestion is carried out in the airtight enclosures, which helps in containing and controlling the odors of solid and liquid wastes. Digested slurry is completely odorless.

Raw material for biogas

The raw materials for biogas can be waste, cultivated material and harvested material. The waste includes industrial waste, agricultural crop residues and waste, animal waste, urban waste, aqua waste and forest waste. Agricultural crops include rice, wheat and cereals while agricultural wastes include wheat straw, sugarcane biogases, groundnut shell, coconut shell and rich husk. Animal wastes include cow dung, horse manure, sheep manure and poultry waste. Urban wastes include paper, leftover food, plastic, rubber, wood and textile. Aqua wastes include water plants (hyacinth), algae and waste from fishery. Forest wastes include waste from sugar mill, tannery, fruit processing industry and paper mill.

Factors affecting the performance of digester

The factors affecting the performance of a digester are as follow:

(i) *Temperature*. Anaerobic bacteria grow and work best in the temperature range of 20-65°C.

(ii) *Pressure.* A pressure of 6-10 cm of water column is considered ideal for proper functioning of the digester.

(iii) *Water*. The presence of water helps in better mixing of various constituents of the biomass, hydrolysis of biomass, movement of bacteria and faster digestion process. The optimum solid content of biomass is 9-10%.

(iv) *pH value*. The pH value in the acid forming stage of digestion process should be about 6 (acidic). During methane forming stage, the pH value should be about 6.5-7.5 as anaerobic bacteria do not grow in acidic solution.

(v) *Feeding rate*. A uniform feeding rate should be maintained. In case of faster feed, acids will accumulate to stop digestion process. In case of slow feed, the digestion progresses slowly due to non-availability of sufficient biomass.

(vi) *Presence of nutrients*. Carbon, nitrogen and other nutrients are essential for digestion. Carbon and nitrogen are main nutrients for anaerobic bacteria and their presence in proper ratio is essential to ensure the maximum microbiological activity. Selected raw materials should added to maintain the proper concentration of nutrients in digestion solution of bacteria.

(vii) *Seeding*. To start or accelerate the digestion process, it is customary to add a small amount of digested slurry containing methane forming bacteria to the freshly charged digester. This process is called seeding of bacteria.

(viii) *Mixing and stirring*. Mixing and stirring of digester slurry helps to mix the floating masses of biomass in the slurry for bacterial action so as to speed up the methane forming process in the slurry.

(ix) *Retention time*. It is the duration for which the biomass slurry remains in the digester. The digesters are designed to keep biomass for the retention period ranging from 30 to 50 days depending on the region (climatic temperature) and type of biomass. Retention time is optimized to get at least 70-80% of digestion of the slurry.

(x) *Toxic substances*. The presence of pesticides, detergents and ammonia in the biomass affects the digestion process.

(xi) *Type of biomass*. The digestion process also depends on the type of biomass. The biomass can be cow dung, poultry manure, sheep manure, night soil, rice husk, algae and water hyacinth and these have a different rate of biogas yield per unit mass.

7.4.3 *Main components of biogas plants*

List and explain the main components of biogas plant

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

(i) *Digester:* **A digester is also called as "fermentation tank" and is mostly** embedded partly or fully in the ground. It is generally cylindrical in shape and is made of bricks. It holds the slurry for a sufficiently long time to complete the digestion.

(ii) *Gas holder:* Its function is to keep the gas subsequent use. The gas connection for use is taken from the top of the gas holder. In some designs of biogas plants, it may be separable from the digester where as in other designs it may be an integral part of the digester.

(iii) *Inlet*: An inlet is provided to add the mixture of dung and water to digester, and is sloped accordingly.

(iv) *Outlet*: The provision of outlet is made to take out the digested portion of slurry.

(v) *Slurry mixing tank*: This tank carries out mixing of the dung with water for induction in the digester, through the digester.

(vi) *Stirrer*: The stirrers are provided in the biogas plants of large size for stirring the slurry for fermentation inside the fermentation chamber to ensure the normal production of gas.

The small size biogas plants can function without a stirring device. Some biogas plants also have the arrangement of external heating by solar/electrical energy etc under colder climates. The biogas plants are built in several sizes, small (0.5 m^3/day) to very large (2500 m^3/day). Accordingly, the configurations are simpler and complex.

4. *Classification of biogas plants*

- How biogas plants are classified? Explain them briefly.
- Name various models of biogas plants and describe any one of them. Write a note on dome type biogas plant.
- Explain the availability and conversion theory of a biogas plant.
- Explain the differences between fixed dome type and floating drum type biogas plants.
- Write the advantages and disadvantages of floating drum type and fixed dome type biogas plants.

Biogas plants can be classified as batch type and continuous type. The continuous type biogas plants can be further classified as (i) floating drum or constant pressure type plant and (ii) fixed dome or constant volume type plant.

Batch type plant

A batch type plant consists of a number of digesters which are charged, used and emptied one by one in a synchronous manner to maintain regular supply to gas holder or storage tank. Each digester is charged with fresh biomass and it starts supplying biogas after 8-10 days. The digester is now capable of supplying biogas for about 40-50 days till its biomass is completely digested. Afterwards, this digester is emptied and recharged with fresh biomass. Hence, each digester should be charged in about at the interval of 50-60 days. Digester in a batch biogas plant is shown in the Figure 7.4. The installation and operation of batch type plant is both capital and labor intensive.

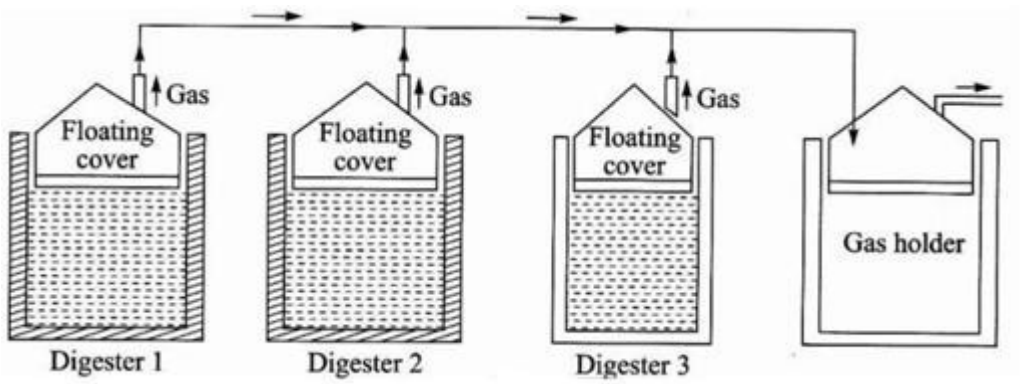


Figure 7.4 batch type plant with number of digesters and a gas holder

Continuous type biogas plant

In continuous type biogas plant, a certain quantity of biomass slurry is fed daily into the digester. This is made possible by the removal of digested slurry through an outlet so that the digester can have space to intake fresh biomass slurry. The biogas produced is either stored in the digester or removed to be stored in a gas holder. The plant operates continuously and it is stopped only for the removal of sludge. The layer of scum at the top of the biomass slurry is periodically broken with the help of the stirrer as shown in Figure 7.5. The stirring also helps in better mixing of biomass slurry to speed up the digestion process. This type of plant is most suitable for individual house owners as the daily wastage can meet the biomass feed requirement of the digester.

Fixed drum type biogas plant

The plant consists of an inverted metallic drum to function as gas holder and an underground digester constructed from masonry with a partition wall as shown in Figure 7.6. The digester chamber is provided with a partition wall at the centre so that optimum conditions for growth of acid forming bacteria and methane forming bacteria can be provided in the partitioned portions as biomass slurry should be acidic and basic for acid forming and methane forming bacteria, respectively. The pipe arrangements are provided to the digester for the supply of fresh feed of biomass slurry and the removal of digested slurry. As the digester has floating gas holder, the pressure inside the digester remains constant. There is no risk of explosion due to prevailing low pressure of gas.

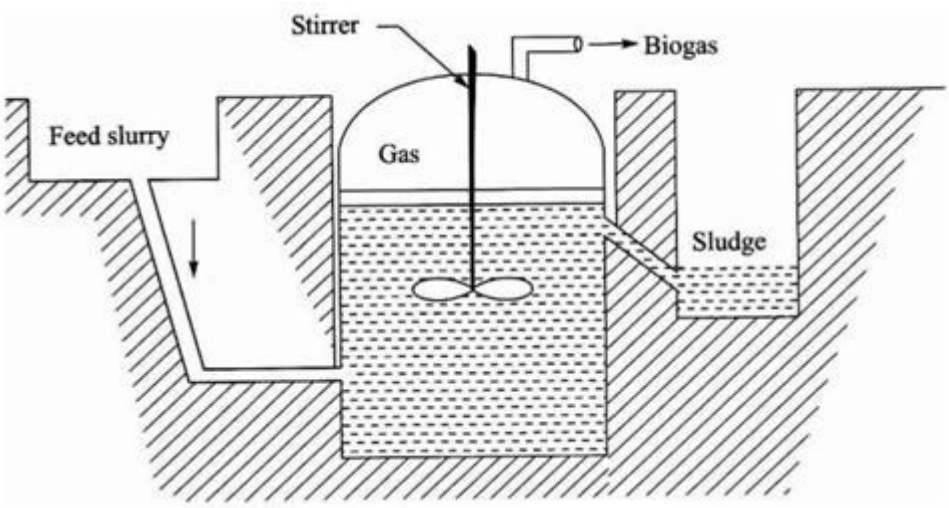


Figure 7.5 Continuous type biogas plant

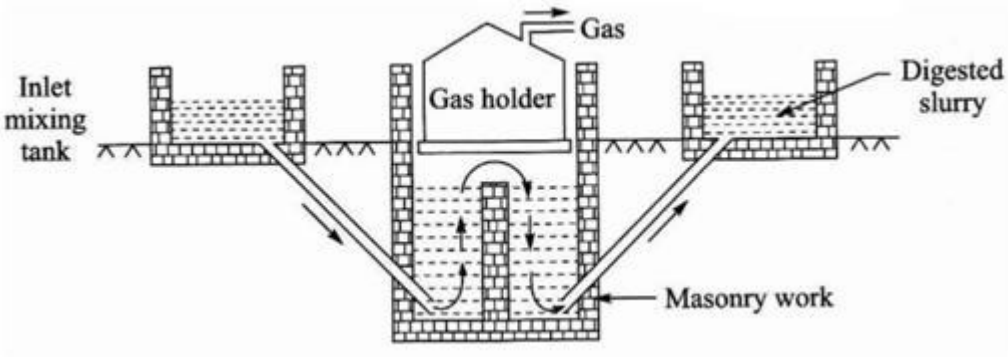


Figure 7.6Floating drum type biogas plant

Fixed dome type biogas plant

It has constant volume but varying pressure inside the digester as it has no movable type gas holder but a fixed dome at the upper portion of the digester as shown in Figure 7.7. The biomass and water are mixed into slurry in inlet mixing tank, which is fed into the digester through the inlet pipe. A stirrer is provided in the digester tank to mix the slurry inside the digester, which also helps in mixing of scum floating on the slurry. The generated biogas accumulates in the fixed dome of the digester and it is taken out by an outlet pipe. The residual digested slurry is taken out from an opening in the digester. In the modified fixed dome type biogas plant, a displacement tank is also provided which is connected to the digester. As the pressure of gas in the fixed dome increases, the level of the slurry inside the digester goes down and it forces the slurry to rise in the displacement tank. This arrangement helps in maintain a constant pressure inside the digester about 1 m of water column and the removal of digested slurry from the displacement tank.

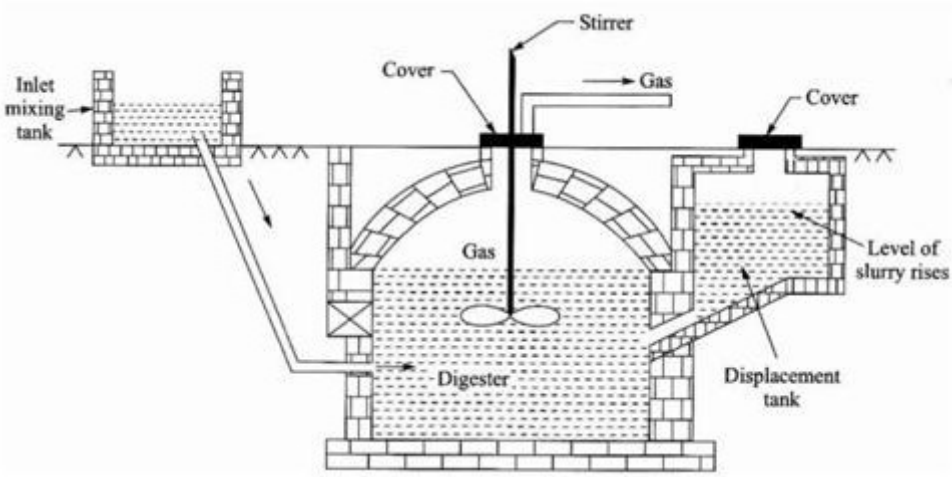


Figure 7.7 Fixed dome type biogas plant

Comparison of floating drum and fixed dome types of plants.

The comparison of floating drum and fixed dome biogas plants is given in the table

Table - comparison between floating drum and fixed drum

Floating drum	Fixed dome
1. It has constant pressure in the digester	1. It has constant volume in the digester
2. The pressure in the digester is slightly more than the atmospheric pressure	2. The pressure inside the digester can be as high as 1 m of water column
3. No danger of explosion of gas as pressure in the digester is low	3. Danger of explosion exists as pressure is high
4. No danger of leakage of gas	4. Due to high pressure there is danger of leakage of gas
5. Cost is more due to floating steel drum provision	5. Less costly
6. Corrosion of steel floating drum is likely	6. No such danger.
7. More maintenance needed due to sliding metallic drum	7. Less maintenance needed.
8. Gas production is high due to lower pressure in the digester	8. Low production of gas
9. Installation is simple	9. Installation is difficult

Advantages and disadvantages of floating drum type biogas plant

The advantages are as follows:

1. Higher gas production per cubic meter of digester volume.
2. No gas leakage problem.
3. Constant gas pressure.
4. No danger of gas explosion.
5. No separate pressure equalizing device is needed when fresh feed is added or digested slurry is removed from the digester.
6. Simple installation.

The disadvantages are as follows:

1. It has higher cost due to movable metallic drum.
2. It has corrosion problem in the metallic movable drum provided.
3. It requires more maintenance.

Advantages and disadvantages of fixed dome type biogas plant

The advantages are as follows:

1. It has lower cost.
2. It has no corrosion problem.
3. It has better heat insulation.
4. It requires no maintenance.

The disadvantages are as follows:

1. Gas production per cubic meter of the digester is less.
2. It has variable pressure of biogas.
3. It has more risk of leakage due to higher pressure of gas.
4. It has more risk of explosion.
5. It involves complex installation.

7.4.5 *Byproduct of digestion*

Explain the byproduct of digestion with the help of a schematic diagram.

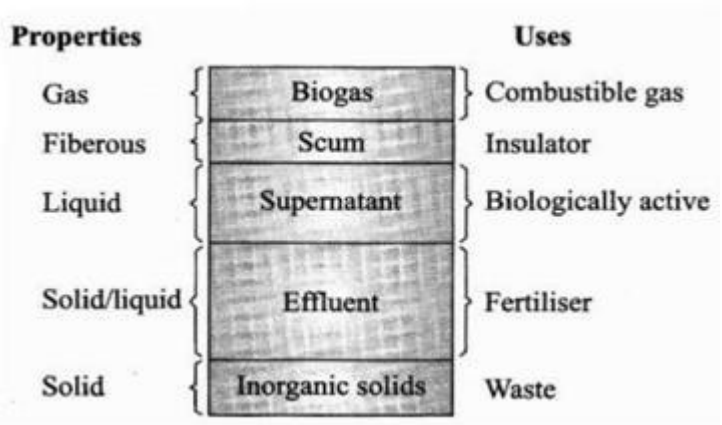


Figure 7.8 byproducts of digestion of biomass

5. Application of biogas in IC Engine

How biogas can be utilized in IC engine.

The properties of biogas are as follows:

(i) **Composition.** Methane 60%, carbon dioxide 40% & traces of hydrogen, hydrogen sulphide and other gases.

(ii) **Calorific value.** Calorific value 5160 kcal/m3 or 4250 kcal/kg.

(iii) **Stoichiometric air fuel ratio.** The stoichiometric $A:F$ ratio is 5.27 by volume

(iv) **Calorific value of mixture.** It is equal to 767 kcal/m3, that is, 85% of gasoline

The biogas alone cannot be used in IC engine unless some modification is carried out in the IC engine. However, with blending of biogas in small amount with both petrol and diesel, it is possible to run IC engine by it with small modification (providing gas kit and supply system). It is found that a mixture of biogas and gasoline containing 5-10% biogas can be successfully used as IC engine fuel, thereby reducing the limited and costly gasoline consumption by 5-10% and at the same time reducing the cost of fuel.

6. *Models of biogas plants*

(i) Common circular digester with floating gas holder without water seal (KVIC design, India).

(ii) Common circular fixed dome digester (China).

(iii) Flexible gas type combined digester and gas holder.

(iv) Taper digester with floating gas holder (Nepal).

(v) Two-chamber rectangular digester with floating gas holder and water seal (Philippines).

(vi) Jet digester with separate gas holder (Thailand).

(vii) Khadi and Village Industries Commission (KVIC) model.

(viii) Planning Research and Action Division (PRAD) model.

(ix) ASTRA (Application of Science and Technology to Rural Areas) model.

(x) Ganesh model.

7.7 Location of biogas plant:

What are the factors considered while locating a biogas plant?

The considerations for locating a biogas plant are as follow:

(i) Do not locate the plant within 13 m of a well or spring used for drinking water purposes.
(ii) Locate the plant near to area where biomass is generated.
(iii) Water source should be available near the site to meet the need of digester.
(iv) The site should be open and exposed to the sun as digester gives better performance at the temperature between 25 and 75°C.
(v) The site should be as close as possible to the point of gas consumption to avoid pressure losses in the pipe system.

7.8 Size of biogas plant:

What is the consideration made to fix the size of biogas plant?

The considerations made to decide the size of the plant are as follows:

(i) How much waste is generated with the number of animals and people?
(ii) How much gas the owners require?
(iii) What will be the volume of the digester tank needed to handle the mixture of biomass and water?
(iv) What is the size and shape of digestion tank required?
(v) What should be the size of the floating drum of the digester?
(vi) What are the requirements of various items for the installation of the digester?

7.9 Problems and constraints in the use of biogas plant:

Why biogas plants are not successful in India even after the subsidies provided by the government of India?

Many problems associated with the biogas programme are putting hinderance to its success. The problems are as follows:

(i) *Technical problems*

Problems caused due to modifications in the design and specification at local level. Lack of temperature control due to poor insulation and seasonal variations. Improper designing and development of appliances. Unsuitability of biogas digester to meet different climatic conditions.

(ii) *Socio-economic problems*

Wood fuel is available free of cost in most rural areas and necessity of biogas plant is not realized villages. Lack of awareness of benefits of biogas plants. Lack of awareness of technology about biogas plants.

(iii) *Installation problems*

Defective construction due to untrained man power Lack of technical knowledge about biogas plants Unavailability of plant components Delay in sanction and disbursement of bank loans. Lack of coordination among government and other agencies involved in biogas programme.

7.10 Community biogas plant:

Write briefly about community biogas plants.

The community biogas plants can help in transforming village life by providing not only efficient cooking fuel but also electricity for

(i) lighting,
(ii) operating cottage industries,

(iii) irrigation,

(iv) supplying drinking water,

(v) maintaining sanitation and fertilizers for improved agriculture.

To improve the productivity and efficiency biogas plants, following suggestions are being considered:

a. Biogas is to be used in dual fuel engine to generate power which can be sold to the state electricity boards.
b. The hot exhaust of power generating system should be used to operate biogas plants at higher temperature, thereby increasing biogas production from a biogas plant.
c. The use of additional materials such as water plants with animal waste to generate biogas.
d. The new methods of biogas generation using bacterial support structures and recycling of spent slurry help in reducing cost of biogas generation.