MAILAM ENGINEERING COLLEGE

MAILAM, VILLUPURAM (DT), PIN: 604304

(Approved by AICTE, New Delhi, Permanently Affiliated to Anna University Chennai

& Accreditation by NBA and Tata Consultancy Service (TCS) Chennai)

DEPARTMENT OF MECHANICAL ENGINEERING

SUBJECT NAME : RENEWABLE ENERGY TECHNOLOGIES

SUBJECT CODE : CME365

YEAR & SEMESTER : III / V

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PRINCIPAL

CME365 RENEWABLE ENERGY TECHNOLOGIES

UNIT – I ENERGY SCENARIO

Indian energy scenario in various sectors – domestic, industrial, commercial, agriculture, transportation and others – Present conventional energy status – Present renewable energy status- Potential of various renewable energy sources-Global energy status-Per capita energy consumption - Future energy plans.

UNIT – II SOLAR ENERGY

Solar radiation – Measurements of solar radiation and sunshine – Solar spectrum - Solar thermal collectors – Flat plate and concentrating collectors – Solar thermal applications – Solar thermal energy storage – Fundamentals of solar photo voltaic conversion – Solar cells – Solar PV Systems – Solar PV applications.

UNIT – III WIND ENERGY

Wind data and energy estimation – Betz limit - Site selection for windfarms – characteristics - Wind resource assessment - Horizontal axis wind turbine – components - Vertical axis wind turbine – Wind turbine generators and its performance – Hybrid systems – Environmental issues - Applications.

UNIT – IV BIO-ENERGY

Bio resources – Biomass direct combustion – thermochemical conversion - biochemical conversionmechanical conversion - Biomass gasifier - Types of biomass gasifiers - Cogeneration – - Carbonisation – Pyrolysis - Biogas plants – Digesters –Biodiesel production – Ethanol production - Applications.

UNIT – V OCEAN AND GEOTHERMAL ENERGY

Small hydro - Tidal energy – Wave energy – Open and closed OTEC Cycles – Limitations – Geothermal energy – Geothermal energy sources - Types of geothermal power plants – Applications - Environmental impact.

OUTCOMES: At the end of the course the students would be able to
1. Discuss the Indian and global energy scenario.
2. Describe the various solar energy technologies and its applications.
3. Explain the various wind energy technologies.
4. Explore the various bio-energy technologies.
5. Discuss the ocean and geothermal technologies.

TEXT BOOKS:
1. Fundamentals and Applications of Renewable Energy | Indian Edition, by Mehmet Kanoglu, Yunus A. Cengel, John M. Cimbala, cGraw Hill; First edition (10 December 2020), ISBN-10 : 9390385636
2. Renewable Energy Sources and Emerging Technologies, by Kothari, Prentice Hall India Learning Private Limited; 2nd edition (1 January 2011), ISBN-10 : 8120344707

UNIT – I ENERGY SCENARIO

Indian energy scenario in various sectors – domestic, industrial, commercial, agriculture, transportation and others – Present conventional energy status – Present renewable energy status-Potential of various renewable energy sources-Global energy status-Per capita energy consumption-future energy plans.

Indian energy scenario in various sectors

1. What is energy?

Energy is the ability to do work .Scientists define energy as the ability to do work. Modern civilization is possible because people have learned how to change energy from one form to another and then use it to do work.

There are many forms of energy:

- Heat
- Light
- Motion
- Electrical
- Chemical
- Gravitational

2. Give the outline of World energy use.

World energy consumption refers to the total energy used by all of human civilization. Typically measured per year, it involves all energy harnessed from every energy source applied towards humanity's endeavors across every single industrial and technological sector, across every country.

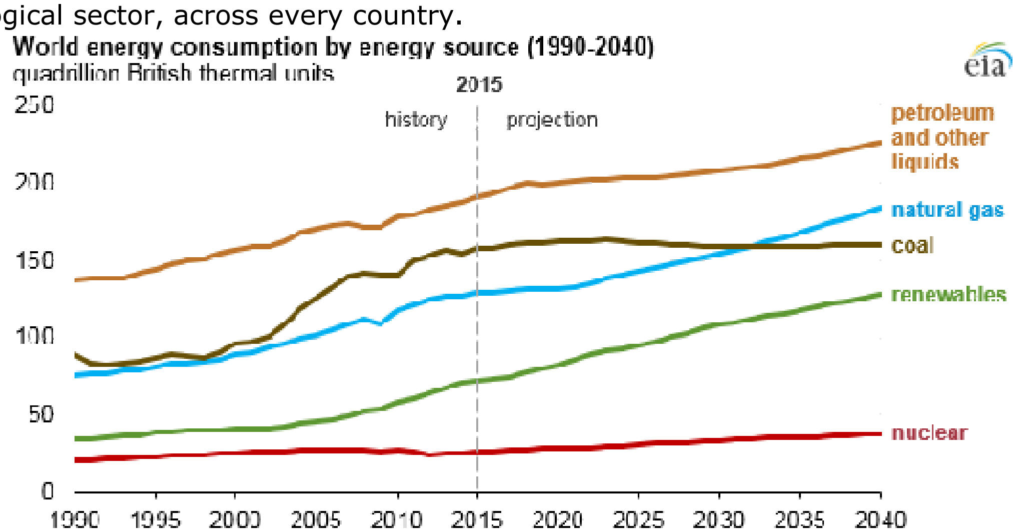


Fig.1.1. World Energy consumption by energy source

3. Give an outline of energy resources in Tamil Nadu.

In India, Tamil Nadu is the only state where one-third of the installed power comes from renewable sources. The present installed capacity of 17,868.37 MW mostly consists of

- Coal (35%),
- Hydro (12%)
- Renewable Energy (42%)

Tamilnadu higher percentage of renewable energy comes from the fact that State has geographic conditions that are suitable for harnessing such sources of energy.

Commercial, agriculture, transportation and others

4. **What is energy scenario for Domestic?**

Coal is the predominant energy source for power production in India, generating approximate- 70% of total domestic electricity. Energy demand in India is expected to increase over the next 10-15 years; although new oil and gas plants are planned, coal is expected to remain the dominant fuel for power generation.

Industrial

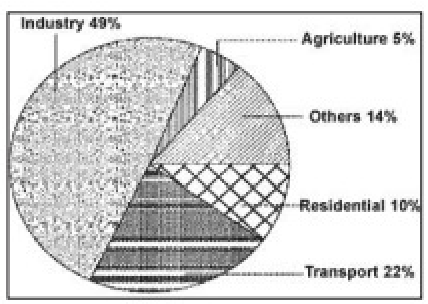
5. **What is energy scenario for Industrial?**

Industry sector accounted for the highest share of energy consumption across India in fiscal year 2021,at 41 percent. The domestic sector followed, ranking second at 26 percent. By comparison, traction and railways accounted for one percent of the total electricity consumption in India .

Commercial

6. **What is energy scenario for commercial?**

The major commercial energy consuming sectors in the country are classified as shown in the Figure. As seen from the figure, industry remains the biggest consumer of commercial energy and its share in the overall consumption is 49%. (Reference year: 1999/2000)



Sector Wise Energy Consumption (1999-2000)

Agriculture, transportation

7. **What is energy scenario for Agriculture?**

Agriculture sector in India has seen tremendous growth in the last 75 years owing to various initiatives to improve food security and raise agricultural output. However, the rise in agriculture output is not directly related to the rise in farm households' income. As per National Sample Survey Office, one-fifth of rural households primarily engaged in agriculture have income less than the poverty lines. To boost the income of cultivators, the Government of India has released a strategy in 2018 - Doubling Farmers' Income. The strategy aims to double the farmers income by 2022 with an annual growth rate of 10.4%.

For certain crops, agriculture is an extremely water-intensive activity. Out of the total electricity consumed in the country, 20% of the electricity is used for agriculture practices, mostly in irrigation. This account of electricity consumed in agriculture can go up to 50% of total consumption in some of the states. As the climatic conditions are turning out to be erratic, irrigation's dependence on monsoon has decreased and the dependence on groundwater has increased. As a result, irrigation now consumes 90% of country's groundwater.

8.What is energy scenario for Transportation?

The transport sector has been a significant consumer of energy in India, especially oil. In 2020, the transport sector consumed around 4 EJ of energy, which was 19 per cent of the final energy consumed by India.

Present conventional energy status

9.What is conventional energy?

The energy sources that once exhausted, do not replenish themselves within a specific period are called conventional or non-renewable energy sources like coal, gas, and oil. For a long time, these energy sources have been used extensively to meet the energy demands.

10. What is non conventional energy?

Define Non- Conventional Sources of Energy. Wind, tides, solar, biomass and other natural resources provide energy, referred to as "non-conventional resources." Nonconventional energy (or) renewable energy sources are energy sources that are continuously produced in nature and are limitless.

11. Types of Conventional Sources of Energy.

Coal
Oil
Petroleum and Natural Gas
Fuel Woods
Thermal Power Plant
Nuclear energy

13.What is the status of conventional energy sources?

Over 80%of India's energy needs are met by three fuels: coal, oil and solid biomass. Coal has underpinned the expansion of electricity generation and industry, and remains the largest single fuel in the energy mix.

14. What is the percentage of conventional energy sources India's?

In 2020, India used 77% fossil fuels for its electricity generation, of which 72.5% came from coal, 4.2% came from natural gas and 0.3% came from oil. Considering India's overall energy demand, not just electricity, renewable and nuclear power only made up a share of 4% of the country's energy mix in 2020.

Present renewable energy status

15. What is renewable energy Resources?

Renewable sources of energy can be used over and over again. Renewable resources include solar energy, wind, geothermal energy, biomass and hydropower. They generate much less pollution, both in gathering and production, than nonrenewable sources.

17.What are Roles of Renewable Energy Sources in India?

The major role of the government to maintain a sustainable balance in all sources of energy. There are various types of status is being maintained they are

- Solar Energy Status
- Bio Mass Energy Status
- Geo Thermal Energy Status
- Ocean Wave Energy
- Wind Energy Status
- Ocean Energy Status
- Ocean Tide Energy

18.What are present Renewable Energy Sources in India?

India stands 4th globally in Renewable Energy Installed Capacity (including Large Hydro), 4th in Wind Power capacity & 4th in Solar Power capacity as per REN21 Renewable 2022 Global Status Report.

19.What is the Renewable energy capacity India 2023?

India currently has a total renewable energy capacity of 168.96 GW (as on 28th February 2023) with about 82 GW at various stages of implementation and about 41 GW under tendering stage.

Potential of various renewable energy sources

20. What is Potential of various renewable energy sources?

The country has an estimated renewable energy potential of around 85,000MW from commercially exploitable sources, wind 45,000 MW small hydro, 15,000MW and biomass/bio energy, 30,000 MW. In addition, India has the potential to generate 35MW per square kilometer using solar photovoltaic and solar thermal energy. There has been phenomenal progress in wind power and, with an installed capacity of over 15700 MW India occupies the fifth position globally.

Global energy status

21.What is global energy?

The energy we use to support the whole range of human activities comes from a variety of sources, but as you all know, fossil fuels (coal, oil, and natural gas) currently provide the majority of our energy on a global basis, supplying about 81% of the energy.

Per capita energy consumption

21. What is meant by Per capita energy consumption?

The best way to compare energy consumption is by determining how much energy is used on average based on the population. The energy consumption per capita is when the total energy consumption is divided by the total population.

Future energy plans

22. What is the future energy plans India?

According to the Planning Commission, energy requirements of the country are expected to grow at 5.6-6.4% per annum over the next few years. The share of imports of oil is also expected to increase to 90-93% of demand by 2030 from the current level of 73%.

Part-B

Indian energy scenario in various sectors – domestic, industrial, commercial, agriculture, transportation

1. Explain about Indian energy scenario in various sectors.

Domestic

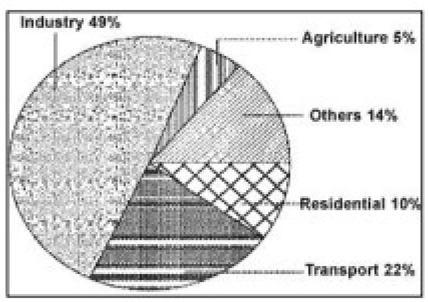
Coal is the predominant energy source for power production in India, generating approximate- 70% of total domestic electricity. Energy demand in India is expected to increase over the next 10-15 years; although new oil and gas plants are planned, coal is expected to remain the dominant fuel for power generation.

Industrial

Industry sector accounted for the highest share of energy consumption across India in fiscal year 2021,at 49 percent. The domestic sector followed, ranking second at 26 percent. By comparison, traction and railways accounted for one percent of the total electricity consumption in India .

Commercial

The major commercial energy consuming sectors in the country are classified as shown in the Figure. As seen from the figure, industry remains the biggest consumer of commercial energy and its share in the overall consumption is 49%. (Reference year: 1999/2000)



Sector Wise Energy Consumption (1999-2000)

Agriculture

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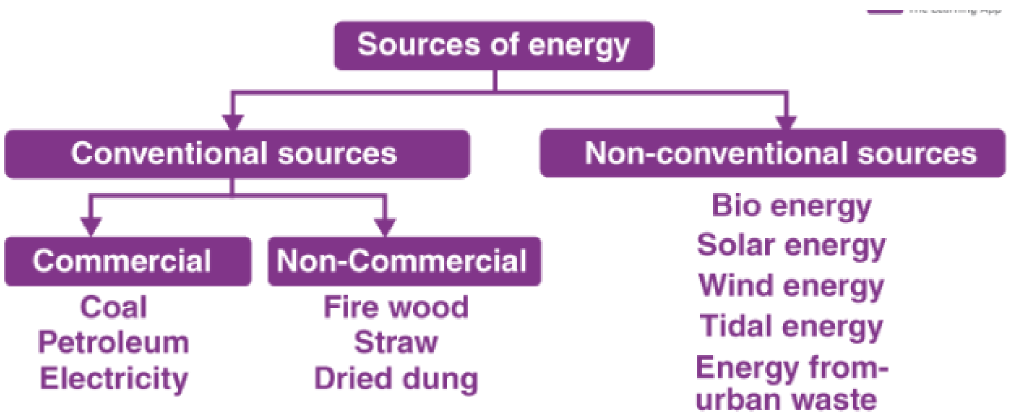
Transportation

The transport sector has been a significant consumer of energy in India, especially oil. In 2020, the transport sector consumed around 4 EJ of energy, which was 19 per cent of the final energy consumed by India.

Present conventional energy status

2. Explain about conventional energy.

Conventional energy: The energy sources that once exhausted, do not replenish themselves within a specific period are called conventional or non-renewable energy sources like coal, gas, and oil. For a long time, these energy sources have been used extensively to meet the energy demands.



Conventional Sources of Energy are also known as non-renewable sources of energy and are available in limited quantity apart from hydro-electric power. Further, it is classified under commercial and non-commercial energy.

Commercial Energy Sources

Coal, electricity and petroleum are known as commercial energy since the consumer needs to pay its price to buy them.

Coal

Coal is the most important source of energy. There are more than 148790 coal deposits in India, and between 2005-2006, the annual production went up to 343 million tons. India is the fourth-largest coal-producing country, and the deposits are primarily found in Bihar, Orissa, Madhya Pradesh, Jharkhand and Bengal.

Oil and Natural Gas

Oil is considered liquid gold and one of the crucial energy sources in India and the world. Oil is primarily used in planes, automobiles, trains and ships. The total oil production in India was 0.3 million tons in 1950-51, which increased up to 32.4 million tons in 2000-01. It is mainly found in Assam, Gujarat and Mumbai.

Electricity

Electricity is a common form of energy used for domestic and commercial purposes, and it is mainly utilized in electrical appliances like fridges, T.V, washing machines and air conditioning.

The major sources of power generation are:

Nuclear Power

Thermal Power

Hydro-electric power

Thermal PowerThermal power is generated at various power stations utilizing oil and coal. It is a vital source of electric current, and its share in the nation's total capacity in 2004-05 was 70 percent.

Hydroelectric PowerHydroelectric power is produced by constructing dams above flowing rivers like Damodar Valley Project and Bhakra Nangal Project. The installed capacity of hydroelectric power was 587.4 mW in 1950-51 and went up to 19600 mW in 2004-05.

Nuclear PowerThe fuel used in nuclear power plants is Uranium, which costs less than coal. Nuclear power plants can be found in Kaiga (Karnataka), Kota (Rajasthan), Naroura (UP) and Kalapakam(Chennai).

3.Explain about Global Present conventional energy status.

Due to the growing wages and expanding living standards, India is the world's third-largest energy consumer. Since 2000, energy consumption has increased, with coal, oil, and solid biomass still meeting 80% of demand.

Major sources of energy in this type are coal, mineral oil and natural gas, firewood and nuclear power.

1. Coal:

About 6000 billion tons of coal lies under the earth. By now over 200 billion tons had been used. The total coal production in world has increased from 273 crore metric tons in 1980 to 323 crore metric tons in 1986, registering an increase of 18.4%.

Table 1 **Coal producing countries of the world**

1980		1986	
Country	% of world Production	country	% of world Production
1	2	3	4
USA	26.04	USA	22.38
China	21.85	China	27.78
USSR	18.10	USSR	15.88
Poland	7.07	Poland	5.95
U.K.	4.77	U.K.	3.62
South Africa	4.25	South Africa	5.49
India	3.99	India	5.06
F.R. Germany	3.46	F.R. Germany	2.70
Australia	2.70	Australia	4.49
Czechoslovakia	1.04	Czechoslovakia	0.78
Total world	273 Crores Metric ton		323 Crores Metric ton

Coal, besides a prime source of industrial energy is also a raw material. Coal, including lignite even today accounts for 60% of the country's commercial power requirements. In developed world there is a trend of shift from coal to oil or gas. Major coal fields in India are Raniganj, Jharia, East Bokaro and West Bokaro; Panch-Kanham (Tawa Valley Singrauli, Talcher (Orissa), Chanda-Wardha and Godavari Valley. M.P.,A.P. and Maharashtra. By and large, the quality of Indian coal is rather poor in terms of heat capacity.

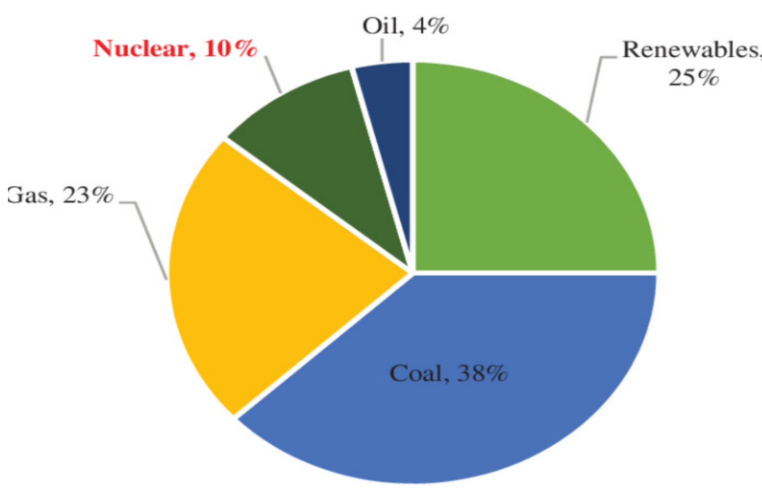


Fig.1.2. world electricity generation by source 2017

This poor hea capacity can be converted into electricity and gas and even oil. This is the reason coal fields to produce electric power to feed regional grids. Coal production in India which was just 35 million tons in 1951 has now gone to cover 180 million tons in 1988-89.

Per capita consumption of coal increased from 135 kg to nearly 225 kg. Lignite (brown coal) is generally a low quality coal. But Indian lignite has less ash content than coal. The deposits at Neyveli (Tamil Nadu) are about 3,300 million tons, about 90% of country's lignite reserves. It produces 600 mw of thermal power.

2. Oil and natural gas:

Sedimentary rocks containing plants animals remains-about 10 to 20 crore year old are the source of mineral oil. Mineral oil is very unevenly distributed over space like any other mineral. There are four regions in the world which are rich in mineral oil. USA, Mexico, former USSR and the West Asian region (Iraq, Saudi Arabia, Kuwait, Iran, United Arab Emirates, Qatar and Bahrain are the major oil producing countries of the world.

It is seen that the oil production has declined from 300 crore metric tons in 1980 to 275 crore metric tons in 1986. India has large proportion of tertiary rocks and alluvial deposits particularly in the extra-peninsular India. Such potential oil bearing area is estimated to be over a million square km, one third of total area. It covers the northern plains in the Ganga-Brahmaputra valley, the coastal strips together, with their off-shore continental shelf (Bombay Hight), the plains of Gujarat, the Thar desert and the area around Andaman and Nicobar Islands.

Till Independence Assam was the only State where mineral oil was drilled. In India, oil was first found at Kakum (north-east Assam) but drilling of oil was started at Digboi in Lakhimpur district. After independence, Gujarat plains and the major reserves were founu off the Bombay High (115 km from the shore).

The latest oil deposits have been found in off shore areas off the deltaic coasts of Godavari, Krishna, Kaveri and Mahanadi. The gas reserves are generally found in association with oil fields. However, exclusive natural gas reserves have been located in Tripura, Rajasthan and almost in all off-shore oil fields of Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh and Orissa.

3. Thermal power:

Hydro-electricity comes from a renewable source, water. But thermal power plants use coal, petroleum and natural gas to produce thermal electricity. These sources are of mineral origin and also called fossil fuels. They are exhaustible and polluting.

Electricity, whether thermal, nuclear or hydro is the most convenient and versatile form of energy. This is in great demand in industry, agriculture, transport and domestic sectors. Installed capacity to produce thermal power in 1988-89 in India was about 40 million k w, a little more than twice the capacity to produce hydel power. The actual power generated in 1988-89 was 201 billion units. Against this, hydel power accounted for 53.8 billion units and nuclear power accounted for 5 billion units, in a single year it had risen to 10%.

Both, big and small power stations are scattered all over the country. Electricity produced by them is fed into regional grids. It is proposed to have a single national grid. The grids receive electricity produced from all the four major sources coal, oil, water and nuclear. Total length of lines was 10.000 circuit km. in 1950 that rose to 1, 71,000 circuit km in 1987. Besides, there are high voltage transmission lines of400 kv strength-16,000 km, and 55,855 km of 220 kv strength.

4. Firewood (Fuel wood):

One must combine supply of fire wood and other biomass energy sources. Besides we need technologies for total utilisation of biomass and/or conversion to solid), liquid (liquification) and gaseous (gasification) fuel. According to ABE (1985) the demand for firewood is likely to go up to the order of300-330 Mt. lists such demand State wise.

It may be seen that nearly 70% of firewood demand pertains to the rural areas. Only 50 Mt. of the fuel wood may become available from natural forests. According to NCA for next 15 years or so the average fuel wood contribution from natural forests would be 0.75 t/ ha/year and the rest is to be met from plantations. gives an idea about the same. Whole of the required plantation is to be non-agricultural land, degraded forest land, cultivable wasteland, barren/in cultivable land, permanent pasture and grazing lands.

5. Hydro-power:

Water-energy is the most conventional renewable energy source and obtained from water flow, water falling from a height. Hilly and highland areas are suitable for this purpose, where there is continuous flow of water in large amounts falling from high slopes In the late 18th and early 19th century most industries were located near water-falls. Technology was also developed for use of steam energy.

Hydro-power is a clean, non-polluting source of energy. It can be transmitted to long distance through wires and cables. But, this form of energy cannot be stored for future. Thus, markets arc to be fixed before generation of this form of energy.

Dams are constructed on rivers. Norway, Switzerland, Canada. Sweden and New Zealand harnessed their water resources for water energy. In South America, about 75% of the total electricity consumption comes from water, Japan, USA and former USSR are the loading countries in production of hydro-power.

6. Nuclear power:

This is of course a main source of energy, when the fossil fuel reserves are depleting very fast. A small quantity of radioactive material can produce an enormous amount of energy. For instance, one tonne of Uranium-2.35 would provide as much energy as by three million tone of coal or 12 million barrels of oil. Besides electricity, atomic power is also used as fuel for marine vessels, heat generation for chemical and food processing plants and for spacecraft's.

For atomic energy, we need a nuclear reactor. The decay of fissionable matter produces enormous heat. This is used to make steam and channeled through a turbine connected to an electric generator. There are different types of nuclear reactor.

4.Explain about Present conventional energy status India.

India is the world's third-largest energy consuming country, thanks to rising incomes and improving standards of living. Energy use has doubled since 2000, with 80% of demand still being met by coal, oil and solid biomass

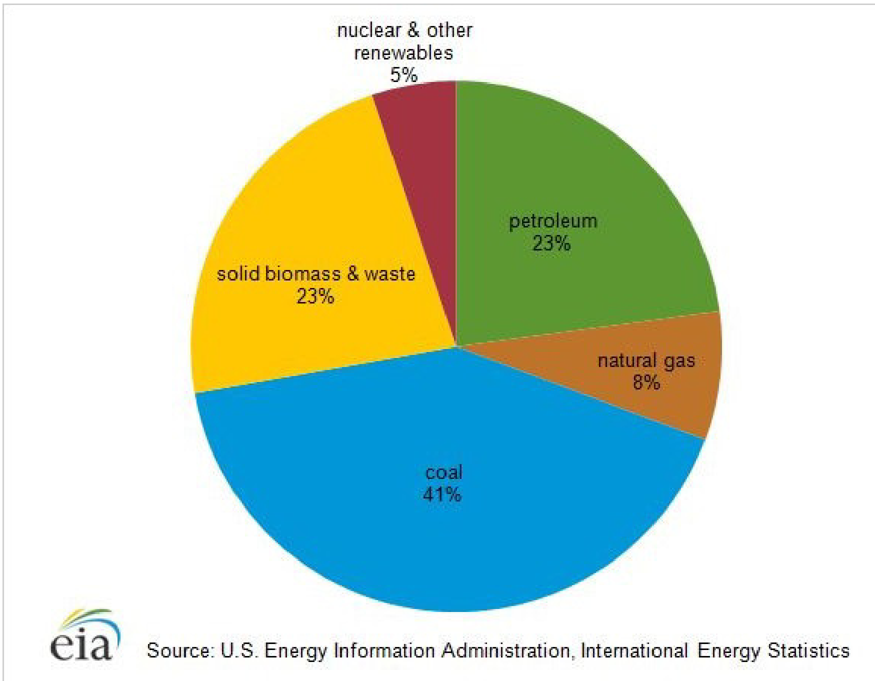


Fig.1.3.Conventional energy status India

Conventional Energy in India

- These are non renewable energy sources that will only be available for a short period of time. These resources will be depleted over time since they are non-renewable.
- Usually derived from decomposing debris that has been around for millions of years.
- The continued exploitation of natural resources has severely harmed them.
- Coal, for example, is a traditional energy source that has been misused and depleted.
- Other than coal, traditional energy sources include biomass, natural gas, and petroleum.
- These sources wreak havoc on the ecosystem and contribute to global warming.
- Commercial and industrial applications are common.
- Involve a lot of money in terms of manufacturing and upkeep. When compared to non-conventional energy sources, it is widely used.
- Fossil fuels, for example, fall into this category since their generation rate is extremely slow (potentially millions of years), making them non-renewable.
- Metallic minerals, unlike coal and petroleum, may be recycled and reused. Once they are completely depleted, it takes millions of years to replenish them.
- Non-commercial energy sources are often defined as those that are freely available. Straw, dried dung, and firewood are examples of non-commercial energy sources.

Coal

- In India, coal is the most easily available fossil fuel. It satisfies a large amount of the country's energy needs.
- It is used to both generate and deliver power to businesses and residences.
- India's commercial energy demands are mainly reliant on coal.
- Coal is formed by the compression of plant material over millions of years.
- As a result, depending on the degree of compression, as well as the depth and duration of burial, coal can be found in a variety of forms.
- In wetlands, decomposing plants generate peat.
- It has a low carbon and moisture content, as well as a restricted heat capacity.
- Lignite is a mushy, low-grade brown coal with a high moisture content. The main lignite deposits are in Neyveli, Tamil Nadu, and they are used to generate electricity.
- Coal that has been excavated deep and subjected to high temperatures is known as bituminous coal. It is the most widely used coal in industry.
- Metallurgical coal is high-grade bituminous coal with a specific use in blast furnaces for smelting iron. The best quality hard coal is anthracite.
- Coke is a dark, rough, porous material. It's carbon that's practically completely free of impurities. Coke is utilised in the production of steel as well as the extraction of a variety of metals.
- Coal gas is created when coal is processed to make coke. It is utilised as a fuel in a number of businesses located near coal-fired power stations.
- As of 2016, India ranked fifth in the world with 107,727 million tonnes of proven coal reserves, accounting for nearly 9% of the world's total coal reserves of 1,139,471 million tonnes.

Petroleum

- The majority of petroleum occurrences in India are connected with anticlines and fault traps in tertiary rock strata.
- It occurs in regions of folding, anticlines, or domes where oil is trapped in the crest of the upfold.
- The oil-bearing layer is a porous limestone or sandstone that allows oil to flow through it. Intervening non-porous layers keep the oil from rising or sinking.
- Petroleum can also be discovered in fault traps formed by porous and non-porous rocks.
- Due to the gas being lighter than oil, it frequently appears above it.
- In India, important petroleum-producing locations are Mumbai High, Gujarat, and Assam.
- The primary source of motive power is petroleum and petroleum products. It's a little, lightweight liquid fuel that's changed the way people travel on land, in the air, and on the sea.
- Tankers can transfer it readily from the producing areas to the consuming areas, but pipelines are more convenient, efficient, and cost-effective.
- It produces extremely little smoke and no ash (as is the case with coal) and may be utilised until the very last drop.
- It is a major raw ingredient for different petrochemical products and supplies the most essential lubricating agents.
- India is the world's third-largest oil consumer, consuming around 4.6 percent of the world's total of 97,103,871 barrels per day.

Natural Gas

- Natural gas is considered an environmentally beneficial fuel due to its minimal carbon dioxide emissions and is hence the fuel of the twenty-first century.
- Natural gas deposits of significant size have been identified in the Krishna-Godavari basin.
- The reserves of the Mumbai High and related fields are enhanced along the west coast by discoveries in the Gulf of Cambay.
- Andaman and Nicobar Islands are also major places with significant natural gas deposits.
- Natural gas is created over millions of years when layers of decaying plant and animal waste are exposed to tremendous heat and pressure under the Earth's surface.
- The energy that the plants get from the sun is stored in the gas in the form of chemical bonds.
- Currently, the manufacturing of fertilisers consumes the majority of natural gas, accounting for around 40% of total consumption.
- About 30% is utilised in electricity generation, while 10% is used in the production of LPG.
- Natural gas production and all of these industries have seen complementary expansion.
- The non-energy use of natural gas, which accounted for 35 percent of overall consumption, included the fertiliser sector, petrochemicals, sponge iron, and LPG shrinkage.

Electricity

- Electricity is produced primarily in two ways: by flowing water, which drives hydro turbines to produce hydroelectricity, and by burning other fuels such as coal, petroleum, and natural gas, which drives turbines to provide thermal power.
- Fast flowing water, a renewable resource, is used to create hydroelectricity.
- Hydroelectric power is produced by a variety of multi-purpose projects in India, including the Bhakra Nangal, Damodar Valley Corporation, and the Kopili Hydel Project.
- Coal, petroleum, and natural gas are used to create thermal electricity.
- Thermal power plants generate energy using nonrenewable fossil sources.
- The gross electricity generated by utilities in India in fiscal year (FY) 2019-20 was 1,383.5 TWh, while total power generation (utilities and non-utilities) was 1,598 TWh.
- Advantages
- Conventional Energy - Advantages
- Conventional Energy has a high energy content. Compared to renewable energy sources such as solar or wind, fossil fuels such as coal and oil tend to give us more energy.
- Coal extraction, oil sales, and natural gas pipeline development may all create substantial profits.
- These resources are simple to utilise in the home or elsewhere.
- Non-renewable resources are available at a low cost to consumers.

- New technologies and other energy sources are unable to replace conventional minerals such as coal and oil for certain individuals. As a result, it is sometimes referred to as traditional energy.
- Conventional energy may be found just about anywhere. This means they can be easily transported throughout the world.
- Non-renewable energy can also be used by those who live in difficult-to-access places.
- Non-renewable resources, above all, are employment creators. The parts of non-renewable sources that create employment include extraction, transportation, and refining.
- The majority of non-renewable resources are also quite simple to store.
- Disadvantages
- Conventional Energy - Disadvantages
- Conventional Energy has a number of drawbacks, one of which is its time-consuming nature.
- Coal mining, oil exploration, oil drilling, oil rig construction, and natural gas extraction and transportation are all time-consuming activities. It also necessitates a significant amount of work.
- Non-renewable energy takes billions of years to create, therefore it is slowly but steadily disappearing from the planet.
- It may be selfish to use nonrenewable resources indiscriminately without considering future generations.
- Due to fossil fuels releasing chemicals like carbon monoxide, nonrenewable energy can be harmful and cause respiratory difficulties in humans.
- Workers in coal mines and oil rigs are more vulnerable to a variety of health hazards. As a result, a great number of infections, injuries, and even fatalities have occurred.
- When coal, oil, and natural gas are burned, a huge amount of carbon dioxide is released. The ozone layer is quickly depleting as a result of these substances.

Present renewable energy status

5. Write a short notes on Renewable Energy Resources

Renewable energy sources include both 'direct' solar radiation intercepted by collectors (e.g. solar and flat-plate thermal cells) and indirect solar energy such as wind, hydropower, ocean energy and biomass resources that can be managed in a sustainable manner.

Geothermal fields tapped with present drilling technologies have a finite life but are sometimes considered renewable for planning purposes.

Traditional methods of using biomass and derivatives such as wood and charcoal are highly inefficient, in contrast with modern techniques emphasing proper forest management sustained yield fuel wood plantations and efficient production.

If broadly interpreted, the definition of renewable resources also includes the chemical energy stored in food and nonfuel plant products and even the energy in air used to dry materials or to cool, heat and ventilate the interiors of buildings.

From an operational view point, the correct way to treat renewable energy is as a means to reduce the demand for conventional energy forms. Thus, in performing economic and financial analyses, there is no real distinction between renewable energy technologies and those designed to improve the efficiency of conventional energy use.

A further point is that cost-effective approaches to energy efficiency-ranging from no-or low-cost measures (e.g. reducing excess air in boilers, shutting down equipment when not needed) to systems requiring moderate capital investment, such as heat recuperators, boiler replacements or cogeneration units, can improve the financial and economic feasibility of renewable as well as conventional energy systems.

Improvements in the efficiency of energy use can be teamed with a variety of energy supply technologies, and this fact must be recognized when assessing the relative economics of renewable and conventional energy systems.

Three independent primary sources provide energy to the earth: the sun, geothermal forces and planetary motion in the solar system.

In particular, direct solar radiation represents an enormous resource for a modern technological civilization. However, human capacity to harness these gigantic natural flows of energy to perform useful work depends largely on the economic feasibility of the required conversion in comparison with fossil fuel options and the extent to which large scale applications affect food production, climate and ecology.

6. What are the Advantages of renewable energy resources?

Even though renewable options are not likely to supply a substantial amount of energy to developing countries over the short term, they do have these advantages:

(1) Renewable energy is an indigenous resource available in considerable quantities to all developing nations and capable, in principle, of having a significant local, regional or national economic impact. The use of renewable energy could help to conserve foreign exchange and generate local employment if conservation technologies are designed, manufactured, assembled and installed locally.

(2) Several renewable options are financially and economically competitive for certain applications, such as in remote locations, where the costs of transmitting electrical power or transporting conventional fuels are high, or in those well endowed with biomass, hydro or geothermal resources.

(3) Because conversion technology tends to be flexible and modular, it can usually be rapid deployed. Other advantages of modular over very large individual units include easy in adding new capacity, less risk in comparison with 'lumpy' investments, lower interest on borrowed capital because of shorter lead times and reduced transmission and distribution costs for dispersed rural locations.

(4) Rapid scientific and technological advantages are expected to expand die economic range of renewable energy applications over the next 8-10 years, making it imperative for international decision makers and planners to keep abreast of these developments.

7. What are the Obstacles to the implementation of renewable energy systems?

Experience with renewable energy projects in the developing countries indicates that there are a number of barriers to the effective development and widespread diffusion of these systems. Among these are:

(1) Inadequate documentation and evaluation of past experience, a paucity of validated field performance data and a lack of clear priorities for future work.
(2) Weak or non-existent institutions and policies to finance and commercialize renewable energy systems. With regard to energy planning, separate and completely uncoordinated organizations are often responsible for petroleum, electricity, coal, forestry, fuel wood, renewable resources and conservation.
(3) Technical and economic uncertainties in many renewable energy systems, high economic and financial costs for some systems in comparison with conventional supply options and energy efficiency measures.
(4) Skeptical attitudes towards renewable energy systems on the part of the energy planners and a lack of qualified personnel to design, manufacture, market, operate and maintain such systems.
(5) Inadequate donor coordination in renewable energy assistance activities, with little or no information exchange on successful and unsuccessful projects.

8. What are the Prospects of Renewable Energy Sources?

The one 'new' source of energy that promises to replace oil and gas, and ultimately coal is a different kind of fusion reactor the sun.

The total amount of incoming solar energy absorbed by the earth and its atmosphere in one year - 3.8×10^{24} J is equivalent to 15 - 20 times

The amount of energy stored in all of the world's reserves of recoverable hydrocarbons. Indeed, if just 0.005% of this solar energy could be captured using fuel crops specially designed buildings, wind and water turbines, solar collectors, have energy converters and the like, this would supply more useful energy over the year than is currently obtained by burning fossil fuels. Unlike capital energy resources, renewable cannot be exhausted. The only limitation is the rate at which they are used it is not possible to deplete any particular reservoir of energy (such as a column of moving air or falling water) faster than it is replenished.

Renewable already supply a major part of the world's energy needs. Biomass, for example, accounts for about one seventh of all fuel consumed, and supplies over 90% of that used in some third world countries: hydro generates one quarter of the World's electricity, and more than two thirds of that used in over 35 countries; and the sun contributes directly to space heating in virtually all buildings, through the walls and windows, although precise estimates of the size of this contribution are not available. However, over the last two decades there has been burgeoning interest in renewable from the more industrialized nations and this has led to growing capital investment.

Renewable energy technologies are in many ways more attractive than most conventional energy technologies.

(i) They can be matched in scale to the need, and can deliver energy of the quality that is required for a specific task, thus reducing the need to use premium fuels or electricity to provide low grade forms of energy such as hot water (which can be supplied in many other ways).

(ii) They can often be built on, or close to the site where the energy is required this minimizes transmission costs.

(iii) They can be produced in large numbers and introduced quickly, unlike large power stations which have long lead times, often 10years or more. Rapid planning and construction lowers unit cost and allows planners to respond quickly to changing patterns of demand.

(iv) The diversity of systems available also increases flexibility and security of supply. In contrast, over dependence on imported fuels makes a country more, vulnerable to political pressures from producer nations and multinationals. Generic faults in power plants, serious breakdowns, industrial action or simply bad weather can jeopardize the supply of electricity.

(v) While there are physical and environmental risks associated with the construction and operation of renewable energy technologies - as there are with all energy conversion systems - they tend to be relatively modest by comparison with those associated with fossil fuels or nuclear power. The failure of a solar panel or a remotely sited wind turbine or wave energy converter might involve temporary inconvenience, but it will not, as a rule, endanger life or limb, nor cause lasting damage. The most serious consequences could be those associated with such events as the catastrophic failure of a large hydro-electric dam, fire in a biomass plantation, or the explosion of a methane digester.

9. Explain about global Present renewable energy status .

India is the 3rd largest energy consuming country in the world

India stands 4th globally in Renewable Energy Installed Capacity (including Large Hydro), 4th in Wind Power capacity & 4th in Solar Power capacity (as per REN21 Renewable 2022 Global Status Report).The country has set an enhanced target at the COP26 of 500 GW of non-fossil fuel-based energy by 2030.

India’s installed non-fossil fuel capacity has increased 396% in the last 8.5 years and stands at more than 179.322 Giga Watts (including large Hydro and nuclear), about 43% of the country’s total capacity (as of July 2023). India saw the highest year-on-year growth in renewable energy additions of 9.83% in 2022.The installed solar energy capacity has increased by 24.4 times in the last 9 years and stands at 67.07 GW as of July 2023. The installed Renewable energy capacity (including large hydro) has increased by around 128 % since 2014.

India is world's 3rd largest consumer of electricity and world's 3rd largest renewable energy producer with 40% of energy capacity installed in the year 2022 (160 GW of 400 GW) coming from renewable source. 2021 Renewable Energy Country Attractiveness Index (RECAI) ranked India 3rd behind USA and China. In FY2023-24, India is planning to issue 50 GW tenders for wind, solar and hybrid projects. India has committed for a goal of 500 GW renewable energy capacity by 2030. In line with this commitment, India's installed renewable energy capacity has been experiencing a steady upward trend. From 94.4 GW in 2021, the capacity has gone up to 119.1 GW in 2023 .

In 2016, Paris Agreement's Intended Nationally Determined Contributions targets, India made commitment of producing 50% of its total electricity from non-fossil fuel sources by 2030. In 2018, India's Central Electricity Authority set a target of producing 50% of the total electricity from non-fossil fuels sources by 2030. India has also set a target of producing 175 GW by 2022 and 500 GW by 2030 from renewable energy.

Solar energy

As of September 2020, 89.22 GW solar energy is already operational, projects of 48.21 GW are at various stages of implementation and projects of 25.64 GW capacity are under various stages of bidding. In 2020, 3 of the world's top 5 largest solar parks were in India including world's largest 2255 MW Bhadla Solar Park in Rajasthan and world's second-largest solar park of 2000 MW Pavgada Solar Park Tumkur in Karnataka and 1000 MW Kurnool in Andhra Pradesh.

Wind power

Wind power in India has a strong manufacturing base with 20 manufactures of 53 different wind turbine models of international quality up to 3 MW in size with exports to Europe, United States and other countries.

Solar, wind and run-of-the-river hydroelectricity are environment-friendly cheaper power sources they are used as ""must-run" sources in India to cater for the base load, and the polluting and foreign-import dependent coal-fired power is increasingly being moved from the "must-run base load" power generation to the load following power generation (mid-priced and mid-merit on-demand need-based intermittently-produced electricity) to meet the peaking demand only. Some of the daily peak demand in India is already met with the renewable peaking hydro power capacity. Solar and wind power with 4-hour battery storage systems, as a source of dispatchable generation compared with new coal and new gas plants, is already cost-competitive in India without subsidy.

India initiated the International Solar Alliance (ISA), an alliance of 121 countries. India was world's first country to set up a ministry of non-conventional energy resources (Ministry of New and Renewable Energy (MNRE) in early 1980s). Solar Energy Corporation of India (SECI), a public sector undertaking, is responsible for the development of solar energy industry in India. Hydroelectricity is administered separately by the Ministry of Power and not included in MNRE targets.

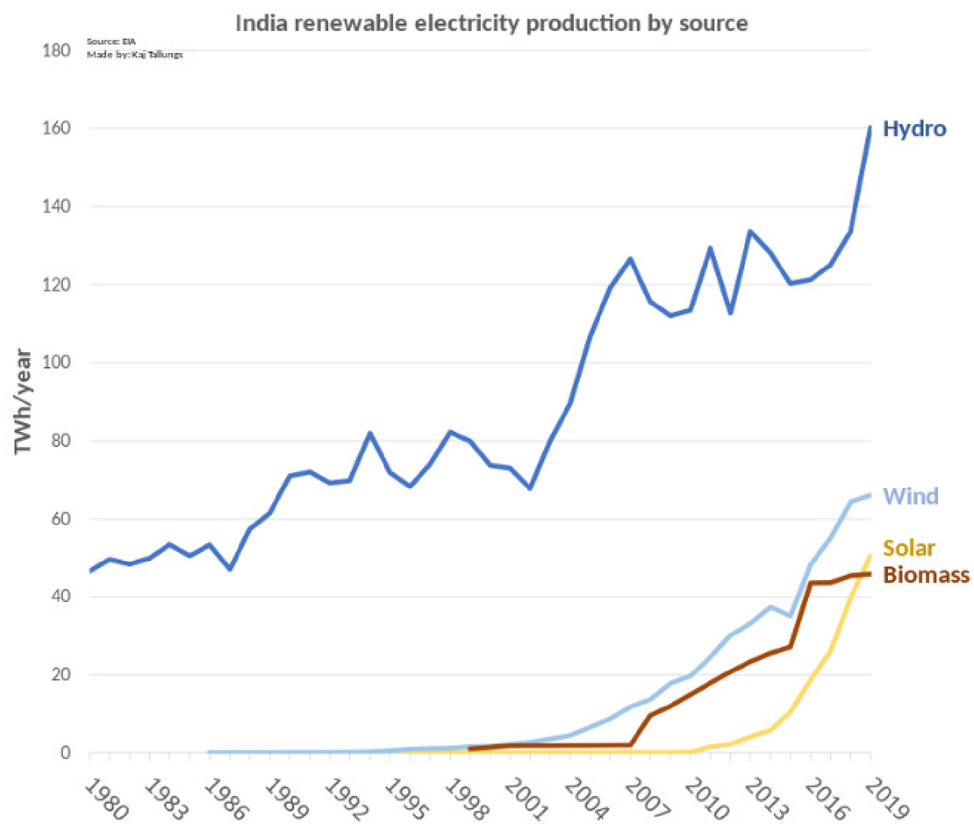


Fig.1.4 India renewable electricity production by source

Tidal energy

As a renewable energy resource, hydro power is one of the most commercially developed. By building a dam or barrier, a large reservoir can be used to create a controlled flow of water that will drive a turbine, generating electricity. This energy source can often be more reliable than solar or wind power (especially if it's tidal rather than river) and also allows electricity to be stored for use when demand reaches a peak. Like wind energy, in certain situations hydro can be more viable as a commercial energy source (dependant on type and compared to other sources of energy) but depending very much on the type of property, it can be used for domestic, 'off-grid' generation.

This is another form of hydro energy that uses twice-daily tidal currents to drive turbine generators. Although tidal flow unlike some other hydro energy sources isn't constant, it is highly predictable and can therefore compensate for the periods when the tide current is low. The tidal energy is a generally form of hydropower, it convert the energy obtained from ocean tide to electrical energy. The tidal energy shown in Fig. 6(A) is obtained from earths oceanic tides. This is one of the cheaper, easily available and environmental friendly energy. The tidal stream is generally used to convert kinetic energy of moving water to power turbines. Tidal energy has the potential to offer the power those we need from fossil fuels. Powerful tides only happen normally 10 h out of each day, this means the tidal energy storage capacity must be developed. Tidal can be harnessed in three different ways; tidal streams, barrages and lagoons. The tidal energy is one of the oldest forms of energy generation. It is a renewable form of energy that converts the natural rise and fall of the tides into electricity. According to the estimates of the Indian government, the country has a potential of 8000 MW of tidal energy. Tidal power surrounds gravitational hydropower, which uses the movement of water to push the turbine to generate electricity

Geothermal energy

By harnessing the natural heat below the earth's surface, geothermal energy can be used to heat homes directly or to generate electricity. Although it harnesses a power directly below our feet, geothermal energy is of negligible importance in the UK compared to countries such as Iceland, where geothermal heat is much more freely available. Geothermal energy is thermal geological energy; it is generated and stored into the earth. The geothermal energy is generally depends upon the geothermal gradient, which is generally depends upon the difference in temperature between the core of planet and its surfaces.

The earth's internal heat is generated from the radioactive decays as shown in Fig. 6(B). The geothermal energy is one of the lower costs, easily available, sustainable, trust worthy and cleans energy. The Vindhyachal Thermal Power Station in the Singrauli district of Madhya Pradesh, with an installed capacity of 4,760 MW, is currently the biggest thermal power plant in India. The International Geothermal Association (IGA) has showed total 10,715 MW of geothermal power is produced by 24 countries in the world (Ruggero, 2007). The geothermal energy is one of the renewable energy sources. The earths internal heat content of 1031 J. Geothermal energy is a renewable energy source because heat is continuously produced inside the earth. People use geothermal heat for bathing, to heat buildings, and to generate electricity. The geothermal field, however, the temperature of geothermal reservoir or the fluid pressure in the reservoir may decrease over time as fluids are produced and energy is extracted (Demkine et al., 2009; Dincer, 1999).

Biomass energy

This is the conversion of solid fuel made from plant materials into electricity. Although fundamentally, biomass involves burning organic materials to produce electricity, and nowadays this is a much cleaner, more energy-efficient process. By converting agricultural, industrial and domestic waste into solid, liquid and gas fuel, biomass generates power at a much lower economic and environmental cost. The biomass is organic matter derived from the leaving materials or organisms. Biomass contains stored chemical energy from the sun. Plants produce biomass through photosynthesis.

Biomass can be burned directly for heating purposes and converted into renewable liquid and gaseous fuels through various processes. The biomass can transform into usable forms of energy like CH_4 gas or ethanol or biodiesels. The annually total biomass produced in the world is around 100 billions. The environmental impact from the production of biomass energy is produced air pollutant like CO, CO_2, NO_x and particulate matter lower comparison to fossil fuels. As per present study the availability of biomass in India is estimated nearly 750 million metric tonnes per year. The thermo chemical conversion of biomass includes pyrolysis and gasification. Both are thermal decomposition processes in which biomass feedstock materials are heated in closed, pressurized vessels called gasifies at high temperatures. The various sources of biomass energy are shown in Fig. 7(A). They depend in the process temperatures and amount of oxygen present during the conversion process

Hydrogen energy

Hydrogen energy is a key role for energy generation and replacing fossil fuels. It is gaining more attention in the future energy source. This is a simple and clean energy source. The hydrogen gas is currently produced from oil, natural gas and coal. The hydrogen gas also produced from biomass by gasification and fast pyrolysis process. The hydrogen gas is normally used for production electricity as shown in Fig. 7(B). The H2 fuel energy contents in terms of mass 120.7 MJ/kg. Globally 95% of hydrogen is produced by hydrocarbon and 4% produced from electrolysis of water (Scott et al., 2004). Hydrogen technologies have practiced cycles of more expectations followed by disillusion. Hydrogen is expected to play a key role as an energy carrier in future energy systems of the world. As fossil-fuel supplies become increases therefore the environmental pollution is also increases, hydrogen is likely to become the major chemical energy carrier. When most of the world's energy sources become non-fossil based, hydrogen and electricity are expected to be the two dominant energy carriers for the provision of end-use services. A transition era will bridge the gap between today's fossil-fuel economy and hydrogen economy, in which the non-fossil-derived hydrogen will be used to extend the lifetime of world's fossil fuels by upgrading the heavy oils. In future the hydrogen energy demand is gradually increased

10.Explain about Present renewable energy status.

Renewable energy sources in India

India has an enormous renewable energy sources. This is the first country around the world to set up a ministry of non-conventional energy sources in early 1980. In India the renewable energy capacity is (excluding the large hydro) has reached 33.8 GW. In these renewable energy sources 66% comes from wind, solar energy participative 4.59% along with biomass and small biomass. In every year 55 million tonnes of municipal solid waste (MSW) and 38 billion liters of sewage generated in urban area of India. It is estimated that waste generated in India will increase at the per capita rate 33% annually. India has a lots of renewable energy sources are available and it discussed .

The availability of renewable energy sources is different from each state in India. Tamil Nadu is one of the largest sources of wind energy in India (Baghali et al., 2021; Ewunie et al., 2021). As of December 31, 2021, the total installed capacity for renewable energy in India is 151.4 GW. The following is the breakup of total installed capacity for Renewable, as of December 31, 2021.

Table 1.2 Total renewable energy source in India 2023

Sources	Total installed capacity (MW)
Wind power	42600
Solar energy	66700
Small hydro power	3990.83
Biomass power	10200
Bagasse power generation	2800.35

Sources	Total installed capacity (MW)
Wade to power	107.58
Total	**33,791.74**

The development for analysis of wind power in India was begun in the 1990s as discussed in, and it increased per year. Today the wind power capacity in India was 20149.50 MW. The Indian government has set the target of adding 18.5 GW of renewable energy sources to generating 11 GW is wind energy. In 2009 India has launched Jawaharlal Nehru National Solar Mission to generate 1000 MW to 20,000 MW solar power energies for production of electricity. The daily average solar power plant generation capacity in India 0.25 kWh/m2 of used land area and total solar electricity production capacity in India 1700–1900 kWh/kWp (kilowatt hours per kilowatt peak) (Chen et al., 2009; Dahiya et al., 2020). The 45 solar parks of aggregate capacity 37 GW have been approved in India.

Total solar parks in Pavagada is 2 GW, Kurnool is 1 GW and Bhadla-II is 648 MW included in top 5 operational solar parks of 7 GW capacity in the country. The world's largest renewable energy park of 30 GW capacity solar-wind hybrid project is under installation in Gujarat. India offers a great opportunity for investments in renewable energy sector; $196.98 billion worth of projects underway in India. The India ranked third globally for total renewable power capacity additions with 15.4 GW in 2021, following China (136 GW) and the US (43 GW). The Green Hydrogen Mission has expected outcome of generating 4.1 million tonnes of annual Green Hydrogen production.

State wise wind energy generating in India (Monroy & Hernandez, 2008; Neudoerffer et al., 2001).

State wise	Wind power
Tamil Nadu	7162.18 MW
Maharashtra	3021.85 MW
Gujarat	3174.58 MW
Karnataka	2135.50 MW
Rajasthan	2684.85 MW
Madhya Pradesh	386 MW
Andhra Pradesh	447.65 MW

State wise	Wind power
Kerala	35.10 MW
West Bengal	1.10 MW

The solar energy is converted into electrical energy with the help of photovoltaic's cells and its capacity in India according to state wise discussed in Table 3 i.e. 7860 MW up to October 2020. Tides are generated by gravitational forces of the sun and the moon on the earth's waters. Tidal energy is a good source of renewable energy, in India total potential of tidal energy was 40,000 MW. In January 2018 Gujrat establishing 310 MW and West Bengal Ganga delta has a 120 MW tidal power project as discussed.

According to study it is estimated that India has used 8000 MW tidal energy. In this also include 7000 MW in the Gulf of Cambay, 1200 MW in the Gulf of Kutch. Sustainable development is possible by use of sustainable energy and by ensuring access to affordable, reliable, sustainable and modern energy for citizens. Strong government support and the increasingly opportune economic situation have pushed India to be one of the top leaders in the world's most attractive renewable energy markets. The government has designed policies, programs and a liberal environment to attract foreign investments to ramp up the country in the renewable energy market at a rapid rate. It is anticipated that the renewable energy sector can create a large number of domestic jobs over the following years. This paper aims to present significant achievements, prospects, projections, generation of electricity, as well as challenges and investment and employment opportunities due to the development of renewable energy in India (Galloway et al., 2017; Ikhlayel, 2018)

State wise installed solar power plant (Koch et al., 2007; Luckow et al., 2010).

State wise	MWp
Andhra Pradesh	279.44
Gujarat	1000.05
Karnataka	104.22
Madhya Pradesh	673.58
Punjab	200.32
Rajasthan	1199.70

State wise	MWp
Tamil Nadu	157.98
Uttar Pradesh	71.26

Tidal energy potential in India (Galloway et al., 2017; Güney & Kaygusuz, 2010).

Region	State	Total Potential (MW)
Gulf of Cambay	Gujrat	7000
Gulf kutch	Gujrat	1200
Ganges Delta, Sunderban	West Bengal	100

State wise biomass power/cogeneration projects (Abbasi et al., 2011; Asumadu-Sarkodie & Owusu, 2016).

State	Power generation (in MW)
Andhra Pradesh	363.25
Bihar	9.50
Chhattisgarh	231.90
Gujarat	0.50
Haryana	35.80
Karnataka	365.18
Madhya Pradesh	1.00
Maharashtra	403.00

State	Power generation (in MW)
Punjab	74.50
Rajasthan	73.30
Tamil Nadu	488.20
Uttarakhand	10.00
Uttar Pradesh	592.50
West Bengal	16.00
Total	**2664.63**

Hydrogen energy is normally used in transportation sector for running a vehicle. It provides long term solution to meet growing energy demand in India while ensuring energy security. It demonstrate one millions hydrogen vehicles, it includes 700,000 two wheelers and 50,000 three wheelers. In the other side the green energy initiatives for power generation set up to installed 1000 MW. The hydrogen based power generation is clean energy and pollution frees. In recent years, the country has developed a sustainable path for its energy supply. Awareness of saving energy has been promoted among citizens to increase the use of solar, wind, biomass, waste, and hydropower energies. It is evident that clean energy is less harmful and often cheaper.

India is aiming to attain 175 GW of renewable energy which would consist of 100 GW from solar energy, 10 GW from bio-power, 60 GW from wind power, and 5 GW from small hydropower plants by the year 2022. Investors have promised to achieve more than 270 GW, which is significantly above the ambitious targets. The promises are as follows: 58 GW by foreign companies, 191 GW by private companies, 18 GW by private sectors, and 5 GW by the Indian Railways. Recent estimates show that in 2047, solar potential will be more than 750 GW and wind potential will be 410 GW.

To reach the ambitious targets of generating 175 GW of renewable energy by 2022, it is essential that the government creates 330,000 new jobs and livelihood opportunities. A mixture of push policies and pull mechanisms, accompanied by particular strategies should promote the development of renewable energy technologies (Palmgren et al., 1999; Prabhakara, 1997).

The H2 gas is storage in pressurized cylinder/tanks. In power generation, hydrogen is one of the leading options for storing renewable energy, and hydrogen and ammonia can be used in gas turbines to increase power system flexibility. Thermal processes for hydrogen production typically involve steam reforming, a high-temperature process in which steam reacts with a hydrocarbon fuel to produce hydrogen. Many hydrocarbon fuels can be reformed to produce hydrogen, including natural gas, diesel, renewable liquid fuels, gasified coal or gasified biomass. India has a largely indigenous nuclear power programmed. In Fig. 11 shown that the Indian government is committed to growing its nuclear power capacity as part of its massive infrastructure development programmed. The government has set ambitious targets to grow nuclear capacity.

Because India is outside the nuclear non-proliferation treaty due to its weapons programmed, it was for 34 year highly excluded from trade in nuclear plant and materials, which hampered its development of civil nuclear energy until 2020. Due to earlier trade bans and lack of indigenous uranium, India has uniquely been developing a nuclear fuel cycle to exploit its reserves of thorium. Since 2021, a fundamental incompatibility between India's civil liability law and international conventions limits foreign technology provision. In March 2018, the government stated that nuclear capacity would fall well short of its 63 GWe target and that the total nuclear capacity is likely to be about 22.5 GWe by the year 2031 (Grover & Chandra, 2004; Kakodkar & Grover, 2004).

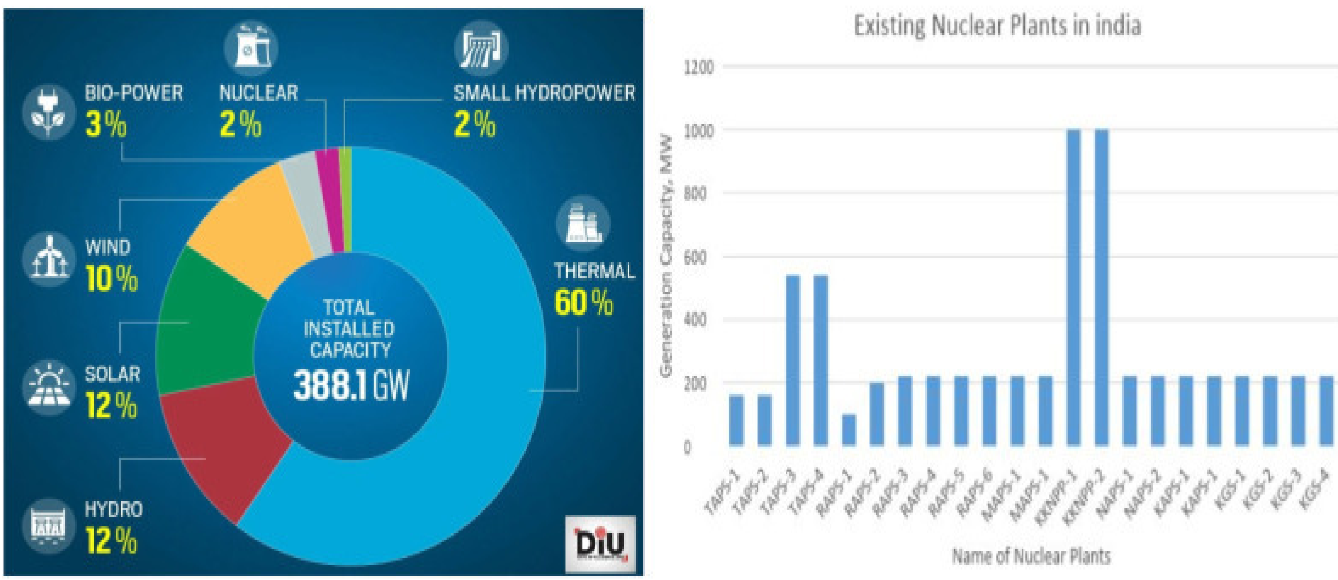


Fig.1.5. Renewable energy sources in India

<u>Potential of various renewable energy sources</u>

11. What are the contribution and potentials of the world energy resources? (or) Describe the various non-conventional energy resources available in India and its potential to supplement the conventional energy sources.

The table contains estimates of the theoretical potential of the world's renewable energy resources and gives an indication of the size of the contribution that each makes to current energy demand. (Geothermal energy is included although it is not strictly a renewable source). The practical and economic potential of renewable is order of magnitude less than the theoretical potential. However, renewable could still meet total world energy demand many times over.

Table . World Renewable Energy Resources

Resource	Form of delivered energy (Application)	Comment
Solar Total solar radiation absorbed by the earth and its atmosphere is 3.8 x 10^{24} J/yr.	Low temperature heat (space heating water heating and electricity)	Millions of solar water heaters and solar cookers are in use. Solar cells and power towers are in operation.
Wind The kinetic energy available in the atmosphere circulation is 7.5 x 10^{20} J	Electricity Mechanical energy (Pumping transport)	Several multi-megawatt wind turbines are in operation and many more in construction. There are numbers of small wind turbines and wind pumps in use.
Biomass Total solar radiation absorbed by plants is 1.3 x 10^{21} J/yr. The world's standing biomass has an energy content of about 1.5 x 10^{22}J.	High temperature heat (cooking, smelting etc.) Bio-gas (cooking, mechanical power etc.) Alcohol (transport)	Biomass (principally wood accounts for about 15% of the world's (commercial fuel) consumption; it provides over 80% of the energy needs of many developing countries. There are millions of biogas plants in operation, most of them are in China. Several thousand, million litres of alcohol are being produced notably in Brazil and the U.S. Production is increasing rapidly ; many countries have lunched liquid biofuel programmes.
Geothermal The heat flux from the earth's interior through the surface ie 9.5 x 10^{20}J/yr. The total amount of heat	Low temperature heat (bathing, space and water heating) Electricity	Geothermal energy supplied about 5350 MW of heat for use in bathing principally in Japan, but also in Hungary, Ice land and Italy. More than a lakh houses are supplied with heat from geothermal wells. The installed capacity is more than 2650 MW (thermal). Installed capacity is more

stored in water or stream to a depth of 10 km is estimated to be 4 x 10^{21} J; that stored in the first 10 km of dry rock is around 10^{27}J.		than 2500 MW but output is expected to increase more than seven fold by 2000.
Tidal Energy dissipated in connection with slowing down the rotation of the earth all a result of tidal action is around 10^{26}. J/yr.	Electricity	Only one large tidal barrage is in operation (at LaRance in France) and there are small schemes in Russia and China. Total installed capacity is about 240 MW and the output around 0.5 TWh/yr. In addition China has several small tidal pumping stations. Several large tidal schemes are being planned.
Wave The amount of energy stored all kinetic energy in waves may be of the order of 10^{18} J.	Electricity	The Japanese wave energy research vessel, the Kaimei, has an installed capacity of about 1 MW. There are, in addition several hundred wave powered navigational buoys. Designs after large prototype wave energy converters are being drawn up.
Hydro The annual precipitation land amounted to about 1.1 x 10^{17} kg of water. Taking the average elevation of land area as 840 m, the annually accumulated potential energy would be 9 x 10^{20} J.	Electricity	Large hydro schemes provide about one quarter of the world's total electricity supply and more than 40% of the electricity used in developing countries. The installed capacity is more than 363 GW. The technically usable potential is estimated to be 2215 GWor 19000 TWh/yr. There are no accurate estimates of the

<u>Global energy status-Per capita energy consumption-future energy plans</u>

12.Explain global energy status and future energy plans india.

Today's energy crisis is delivering a shock of unprecedented breadth and complexity. The biggest tremors have been felt in the markets for natural gas, coal and electricity – with significant turmoil in oil markets as well, necessitating two oil stock releases of unparalleled scale by IEA member countries to avoid even more severe disruptions. With unrelenting geopolitical and economic concerns, energy markets remain extremely vulnerable, and the crisis is a reminder of the fragility and unsustainability of the current global energy system, *the* World Energy Outlook 2022 (WEO) *warns*.

The *WEO*'s analysis finds scant evidence to support claims from some quarters that climate policies and net zero commitments contributed to the run-up in energy prices. In the most affected regions, higher shares of renewables were correlated with lower electricity prices – and more efficient homes and electrified heat have provided an important buffer for some consumers, albeit far from enough. The heaviest burden is falling on poorer households where a larger share of income is spent on energy.

Alongside short-term measures to try to shield consumers from the impacts of the crisis, many governments are now taking longer-term steps. Some are seeking to increase or diversify oil and gas supplies, and many are looking to accelerate structural changes. The most notable responses include the US Inflation Reduction Act, the EU's Fit for 55 package and REPowerEU, Japan's Green Transformation (GX) programme, Korea's aim to increase the share of nuclear and renewables in its energy mix, and ambitious clean energy targets in China and India.

In the *WEO*'s Stated Policies Scenario, which is based on the latest policy settings worldwide, these new measures help propel global clean energy investment to more than USD 2 trillion a year by 2030, a rise of more than 50% from today. As markets rebalance in this scenario, the upside for coal from today's crisis is temporary as renewables, supported by nuclear power, see sustained gains. As a result, a high point for global emissions is reached in 2025. At the same time, international energy markets undergo a profound reorientation in the 2020s as countries adjust to the rupture of Russia-Europe flows.

"Energy markets and policies have changed as a result of Russia's invasion of Ukraine, not just for the time being, but for decades to come," said IEA Executive Director Fatih Birol. "Even with today's policy settings, the energy world is shifting dramatically before our eyes. Government responses around the world promise to make this a historic and definitive turning point towards a cleaner, more affordable and more secure energy system."

For the first time ever, a *WEO* scenario based on today's prevailing policy settings – in this case, the Stated Policies Scenario – has global demand for every fossil fuel exhibiting a peak or plateau. In this scenario, coal use falls back within the next few years, natural gas demand reaches a plateau by the end of the decade, and rising sales of electric vehicles (EVs) mean that oil demand levels off in the mid-2030s before ebbing slightly to mid-century. This means that total demand for fossil fuels declines steadily from the mid-2020s to 2050 by an annual average roughly equivalent to the lifetime output of a large oil field. The declines are much faster and more pronounced in the *WEO*'s more climate-focused scenarios.

Global fossil fuel use has grown alongside GDP since the start of the Industrial Revolution in the 18th century: putting this rise into reverse will be a pivotal moment in energy history. The share of fossil fuels in the global energy mix in the Stated Policies Scenario falls from around 80% to just above 60% by 2050. Global CO2 emissions fall back slowly from a high point of 37 billion tonnes per year to 32 billion tonnes by 2050. This would be associated with a rise of around 2.5 °C in global average temperatures by 2100, far from enough to avoid severe climate change impacts. Full achievement of all climate pledges would move the world towards safer ground, but there is still a large gap between today's pledges and a stabilisation of the rise in global temperatures around 1.5 °C.

Today's growth rates for deployment of solar PV, wind, EVs and batteries, if maintained, would lead to a much faster transformation than projected in the Stated Policies

Scenario, although this would require supportive policies not just in the early leading markets for these technologies but across the world. Supply chains for some key technologies – including batteries, solar PV and electrolysers – are expanding at rates that support greater global ambition. If all announced manufacturing expansion plans for solar PV see the light of day, manufacturing capacity would exceed the deployment levels in the Announced Pledges Scenario in 2030 by around 75%. In the case of electrolysers for hydrogen production, the potential excess of capacity of all announced projects is around 50%.

Stronger policies will be essential to drive the huge increase in energy investment that is needed to reduce the risks of future price spikes and volatility, according to this year's *WEO*. Subdued investment due to lower prices in the 2015-2020 period made the energy sector much more vulnerable to the sort of disruptions we have seen in 2022. While clean energy investment rises above USD 2 trillion by 2030 in the States Policies Scenario, it would need to be above USD 4 trillion by the same date in the Net Zero Emissions by 2050 Scenario, highlighting the need to attract new investors to the energy sector. And major international efforts are still urgently required to narrow the worrying divide in clean energy investment levels between advanced economies and emerging and developing economies.

"It is essential to bring everyone on board, especially at a time when geopolitical fractures on energy and climate are all the more visible," he said. "This means redoubling efforts to ensure that a broad coalition of countries has a stake in the new energy economy. The journey to a more secure and sustainable energy system may not be a smooth one. But today's crisis makes it crystal clear why we need to press ahead."

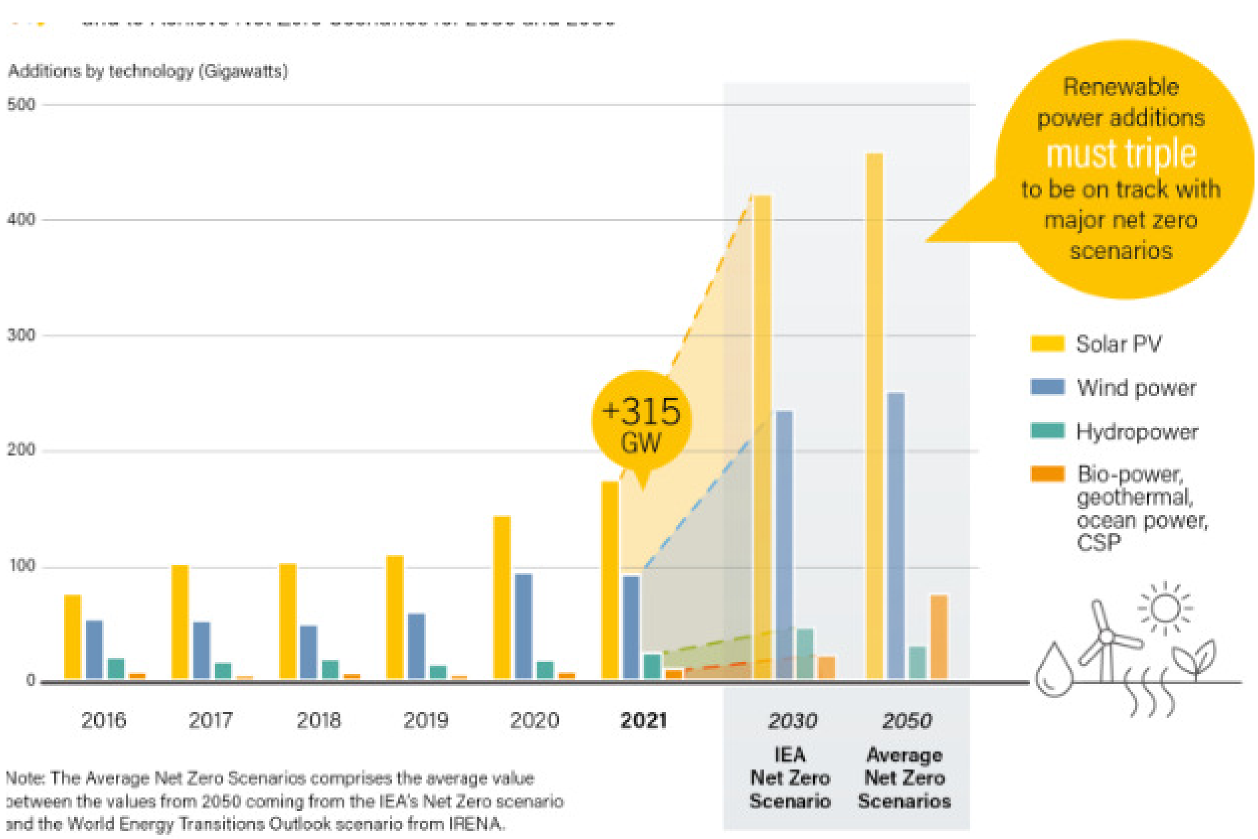


Fig.1.6. Renewable power net zero scenario

Future energy plans India

Renewable electricity is growing at a faster rate in India than any other major economy, with new capacity additions on track to double by 2026. The country is also one of the world's largest producers of modern bioenergy and has big ambitions to scale up its use across the economy.

UNIT – II Solar Energy

Solar radiation – Measurements of solar radiation and sunshine – Solar spectrum - Solar thermal collectors – Flat plate and concentrating collectors – Solar thermal applications – Solar thermal energy storage – Fundamentals of solar photo voltaic conversion – Solar cells – Solar PV Systems – Solar PV applications

Part-A

Solar radiation

1. What is solar radiation?

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies.

2. Where is solar radiation used?

A variety of technologies convert sunlight to usable energy for buildings. The most commonly used solar technologies for homes and businesses are solar photovoltaic for electricity, passive solar design for space heating and cooling, and solar water heating.

3. What do you mean by solar irradiance?

- Solar irradiance is the power per unit area produced by the Sun in the form of electromagnetic radiation. Irradiance may be measured in space or at the Earth's surface after atmospheric absorption and scattering.
- Total solar irradiance (TSI), is a measure of the solar radioactive power per unit area normal to the rays, incident on the Earth's upper atmosphere.

Measurements of solar radiation and sunshine

4. List the instruments used to measure solar radiation. (or) Mention the instruments used for solar radiation and type of solar radiation measured using each instrument. (Nov/Dec 2020)

- **Pyranometers** is used to measure total hemispherical Solar radiation
- **Pyrheliometers** is used to measure Beam Radiation

5. State the application of pyranometer and pyrheliometer.

Pyranometer: Pyrometers are suited especially to the measurement of moving objects or any surfaces that cannot be reached or cannot be touched. Salt bath, thermocouples, metallurgical furnace, steam boiler etc.

Pyrheliometer: Typical pyrheliometer measurement applications include scientific meteorological and climate observations, material testing research and assessment of the efficiency of solar collectors and photovoltaic devices

6. How does a sunshine recorder measure radiation?

Sunshine recorder essentially consists of a glass sphere mounted in a spherical bowl and a metallic groove which holds a record card. Sun's rays are refracted and focused sharply on the record card beneath the glass sphere, leaving burnt marks on the card. As the sun traverses, continuous burnt marks will appear on the card. Observers can measure the sunshine duration based on the length of the burnt marks.

7. List the tools used to measure solar radiation.

Campbell-Stokes sunshine recorder A typical measuring instrument is the Campbell-Stokes sunshine recorder. This consists of a glass ball which focuses the Sun's rays, burning a hole in an index card.

A solar radiometer is a device that accurately measures the sunlight's intensity, according to NASA. Simple mercury thermostats were used to measure sunlight many years ago, but these have been deemed untrustworthy.

8. Give some examples for measuring tools on radiation.

A Geiger counter is an instrument used for detecting and measuring ionizing radiation. Also known as a Geiger–Mueller counter (or Geiger–Müller counter), it is widely used in applications such as radiation dosimeters, radiological protection, experimental physics, and the nuclear industry.

Micro Meter, with Sodium Iodide Detector: A solid crystal of sodium iodide creates a pulse of light when radiation interacts with it. This pulse of light is converted to an electrical signal by a photomultiplier tube (PMT), which gives a reading on the instrument meter.

9.Write note on solar collectors and its types.

- Solar thermal collectors heating water
  - Flat plate collectors
  - Evacuated tube collectors
  - Evacuated flat plate collectors
- Solar thermal collectors heating air
  - Space heating and ventilating
  - Process heating
  - Solar air heating collector types
  - Through-pass air collector
  - Unglazed transpired solar collectors
- Solar thermal collectors generating electricity
  - Parabolic trough
  - Parabolic dish
  - Power tower

10. What are the basic features required in an ideal pyranometer?

A photovoltaic pyranometer is essentially has following parts:

A metallic container with a fixing staff
A small photovoltaic cell
Signal conditioning electronics
Silicon sensors such as the photodiode and the photovoltaic cell vary the output in function of temperature.

Solar spectrum

11. What is solar energy intensity?

Energy from our sun (~1372 W/m^2) is filtered through the atmosphere and is received at the surface at ~1000 watts per square meter or less; average is 345 W/m^2 .The following characteristic are reduce the intensity for received the surface energy.

➢ clouds,

- rain, and
- haze reduce

12. What is solar spectrum?

The solar spectrum is the range of electromagnetic radiation emitted by the sun, extending from the ultraviolet to the infrared region. It is composed of photons with various wavelengths, which define the spectrum's shape and intensity. It can be defined in terms of solar radiation or solar irradiance. Solar radiation is the direct emission of energy from the sun while solar irradiance is the amount of energy that reaches the Earth's surface.

13. What are the three type of solar spectrum?

sunlight is broken down into three major components: (1) visible light, with wavelengths between 0.4 and 0.8 micrometre, (2) ultraviolet light, with wavelengths shorter than 0.4 micrometre, and (3) infrared radiation, with wavelengths longer than 0.8

14.Define Solar declination

The declination of the Sun, δ, is the angle between the rays of the Sun and the plane of the Earth's equator. The Earth's axial tilt (called the obliquity of the ecliptic by astronomers) is the angle between the Earth's axis and a line perpendicular to the Earth's orbit.

The Sun declination angle, δ, is defined to be that angle made between a ray of the Sun, when extended to the centre of the earth, O, and the equatorial plane.

We take δ to be positively oriented whenever the Sun's rays reach O by passing through the Northern hemisphere.

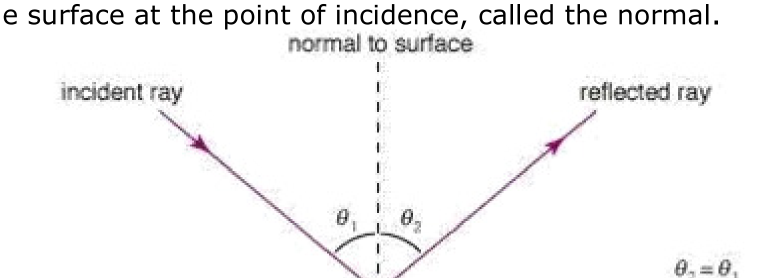
15. What is Solar hour angle?

Solar hour angle is that Observing the sun from earth, the solar hour angle is an expression of time, expressed in angular measurement, usually degrees, from solar noon. ... For example, at 10:30 AM local apparent time the hour angle is -22.5° (15° per hour times 1.5 hours before noon)

The cosine of the hour angle (cos(h)) is used to calculate the solar zenith angle. At solar noon, h = 0.000 so cos(h)=1, and before and after solar noon the cos(± h) term = the same value for morning (negative hour angle) or afternoon (positive hour angle), i.e. the sun is at the same altitude in the sky at 11:00AM and 1:00PM solar time,

16.Define Incident angle

In geometric optics, the angle of incidence is the angle between a ray incident on a surface and the line perpendicular to the surface at the point of incidence, called the normal.



Incident Angle

In order to predict the solar contributions to building cooling loads it is desirable to estimate the solar intensity on typical or average clear days. An estimate of the direct normal solar flux at the earth's surface for an average clear day is:

$$IDN = Ae{-}B \sin\beta$$

where the coefficients A and B are empirically determined from measurements of IDN made on typical clear days. The coefficients can be interpreted as:

A = Apparent direct normal solar flux at the outer edge of the earth's atmosphere

Solar thermal collectors

17. What is a solar thermal collector?

A solar thermal collector collects heat by absorbing sunlight. The term "solar collector" commonly refers to a device for solar hot water heating, but may refer to large power generating installations such as solar parabolic troughs and solar towers or non water heating devices such as solar cooker, solar air heaters.

18. What are the different types of solar thermal collectors?

The whole solar panel absorbs light. Non concentrating solar collectors Concentrating collectors are used for high temperature requirements. Concentrating collectors have a larger interceptor than absorber. Concentrating collectors are used for high temperature requirements.

Flat Plate And Concentrating Collectors

19. What is meant by Solar Energy?

Solar energy is defined as the transformation of energy that is present in the sun and is one of the renewable energies. Once the sunlight passes through the earth's atmosphere, most of it is in the form of visible light and infrared radiation. Plants use it to convert into sugar and starches and this process of conversion is known as photosynthesis. Solar cell panels are used to convert this energy into electricity.

20. List the drawbacks of Solar Energy.

- The large area required to collect the energy at a useful rate.
- The initial cost of purchasing a solar system is fairly high.
- Although solar energy can still be collected during cloudy and rainy days, the efficiency of the solar system drops.
- Solar energy has to be used right away, or it can be stored in large batteries.

21. List out the various type of solar energy.

Solar energy can be classified into two categories depending upon the mode of conversion and type of energy it is converted into. Passive solar energy and active solar energy belongs to the mode of conversion and solar thermal energy, photovoltaic solar power and concentrating solar power.

- Passive solar energy: This refers to trapping sun's energy without using any mechanical devices.
- Active solar energy: This uses mechanical devices to collect, store and distribute the energy.
- Solar thermal energy: This is the energy obtained by converting solar energy into heat.
- Photovoltaic solar power: This is the energy obtained by converting solar energy into electricity.

- Concentrating solar power: This is a type of solar thermal energy which is used to generate solar power electricity.

22. Define solar time.

Solar time (Local Apparent Time) is measured with reference to solar noon, which is the time when the sun is crossing the observer's meridian.

Solar time = Standard time ±4 (L_{st} –L l_{oc}) +E

Where
L_{st} =standard longitude
L_{loc}= longitude of the observer's location
E = Equation of Time
diffused radiation is known as global radiation

23. What is meant by solar collector? Mention its types

A solar collector is a device for collecting solar radiation and transfers the energy to a fluid passing in contact with it. There are two types of collectors:

- Non- concentrating or flat plate type solar collector.
- Concentrating (focusing) type solar collector.
  - Parabolic trough collector
  - Mirror strip reflector
  - Fresnel lens collector
  - Flat plate collector with adjustable mirrors compound parabolic concentrator.

24. Write about solar Stationary concentrating collectors.

Concentrating collectors use mirrored surfaces to concentrate the sun's energy on an absorber called receiver. Concentrating collectors also achieve high temperatures, but unlike evacuated-tube collectors, they can do so only when direct sunlight is available. The mirrored surface focuses sunlight collected over a large area onto a smaller absorber area to achieve high temperatures.

25. Write notes on Flat plate type solar collector.

It consist of (1) a dark flat-plate absorber, (2) a transparent cover that reduces heat losses, (3) a heat transport fluid (air, antifreeze or water) to remove heat from the absorber, and (4) a heat insulating backing. The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminium, steel or copper, to which a matte black or selective coating is applied) often backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover.

26 . Write the various types of concentrating collectors.

- Parabolic trough
- Solar tower
- Parabolic dish
- Linear Fresnel reflector

27. List the components of solar concentrator.

A solar concentrator consists of the following components:

- A reflecting or refracting surface,

- An absorbing surface *i.e.*, an absorber,
- A fluid flow system to carry away the heat,
- A cover around the absorber,
- Insulation for their radiated portion of the absorber and
- A self-supporting structural capability and well-adjusted tracking mechanism.

28. What are the classifications of air heaters?

- The first type has a non-porous absorber in which the air stream does not flow through the absorber plate. Air may flow above and or behind the absorber plate.
- The second type has a porous absorber that includes slit and expanded metal, transpired honeycomb and over-lapped glass plate absorber.
- Unglazed air collectors and transpired solar collectors

29. List the applications of solar air heaters.

- Heating building
- Drying agricultural produce and lumber
- Heating green houses
- Air conditioning building utilizing desiccant beds or a absorption refrigeration process
- Using air heaters as the heat source for a heat engine such as brayton and stirling cycles

30. Explain transmissivity of cover system.

The transmissivity of the cover system of a collector can be obtained with adequate accuracy by considering reflection – refraction and absorption separately and is given by the product form,

$\tau = \tau_r \tau_a$

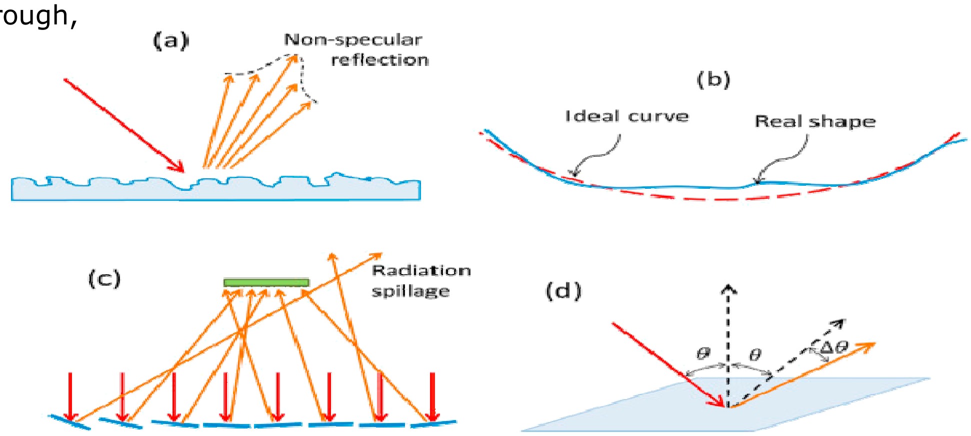
Where,

τ_r- Transmissivity obtained by considering only reflection and refraction

τ_a- Transmissivity obtained by considering only absorption.

31.List out the main types of concentrating collectors.

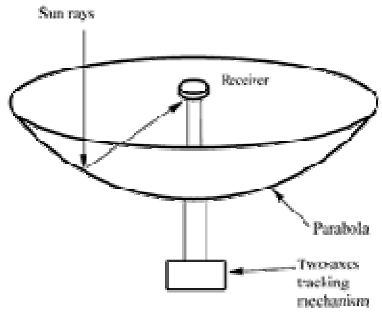
Types of concentrating sunlight collectors
(a) tubular absorbers with diffuse back reflector,
(b) tubular absorbers with specular cusp reflectors,
(c) plane receiver with plain reflectors (V-trough),
(d) multisectional planar concentrator,
(e) compound parabolic concentrator
(f) parabolic trough,



Types of Concentrating Collectors.

32.Explain focus type collector.

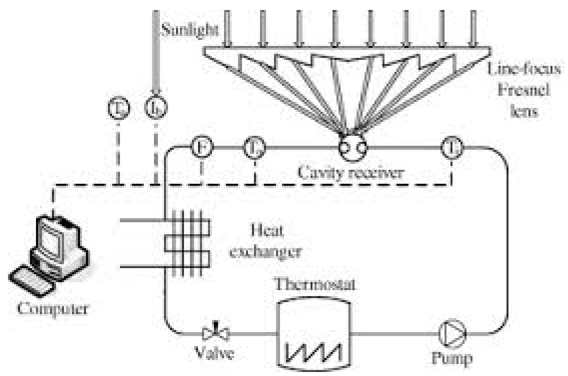
Focusing collector or concentrating type solar collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors generally use optical system in the form of reflectors or refractors. The focus of collector



focus of collector

33.What is Line Focus collector?

These collectors, sometimes known as parabolic troughs , use highly reflective materials to collect and concentrate the heat energy from solar radiation. These collectors are composed of parabolically shaped reflective sections connected into a long trough A pipe that carries water is placed in the center of this trough so that sunlight collected by the reflective material is focused onto the pipe, heating the contents. These are very high powered collectors and are thus generally used to generate steam for Solar thermal power plants and are not used in residential applications.



Line focus collector

34.Define Point focus collector.

These collectors are large parabolic dishes composed of some reflective material that focus the Sun's energy onto a single point. The heat from these collectors is generally used for driving Stirling engines.

Although very effective at collecting sunlight, they must actively track the Sun across the sky to be of any value. These dishes can work alone or be combined into an array to gather even more energy from the Sun

35.Write a short notes cylindrical parabolic collector.

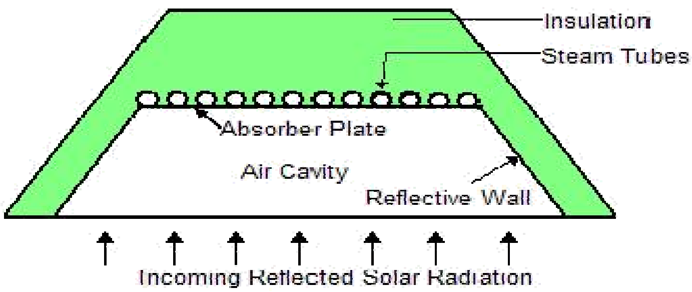
- The cylindrical parabolic collector (CPC) is also referred to a parabolic trough or a Linear parabolic collector is shown on preview.
- The basic elements making up a conventional collector are the absorber tube located at the focal axis through which the liquid to be heated flows, the concentric transparent cover, the reflector,

and the support structure.

- Element and together constitute the receiver, while element and constitute the concentrator.

36.Draw diagram for fixed mirror solar collector and Linear Fresnel lens collector .

A compact linear Fresnel reflector (CLFR) – also referred to as a concentrating linear Fresnel reflector is a specific type of linear Fresnel reflector (LFR) technology. They are named for their similarity to a Fresnel lens, in which many small, thin lens fragments are combined to simulate a much thicker simple lens. These mirrors are capable of concentrating the sun's energy to approximately 30 times its normal intensity**.**



The Fixed Mirror Solar Concentrator (FMSC) is a solar concentrator with static reflector and moving receiver whose design emerged in the seventies as an effort to reduce electricity production costs in solar thermal power plants. Solar concentrators based on this geometry were constructed in the seventies and eighties.

37. What are the important features of a solar collector?

Important features of solar collectors

- Resistance to environmental conditions (marine environment, rain, dust, hail, etc.)
- Large temperature variations
- Anti-leakage from any part of the system
- Stable and durable
- Easy to install
- energy conversion efficiency

38.Define concentration ratio of solar collector. (Nov/Dec 2020)

- ➢ A concentration ratio is the ratio of the combined market shares of a given number of firms to the whole market size. It is common to consider the 3-firm, 4-firm or 5-firm concentration ratio. Concentration ratios are used to assess the extent to which a given market is oligopolistic.
- ➢ The concentration ratio is calculated as the sum of the market share percentage held by the largest specified number of firms in an industry. The concentration ratio ranges from 0% to 100%, and an industry's concentration ratio indicates the degree of competition in the industry. A concentration ratio that ranges from 0% to 50% may indicate that the industry is perfectly competitive and is considered low concentration.

39.List the five advantages of solar energy.

- ➢ Renewable energy source- among all the benefits of solar panels, the most important thing is that solar energy is a truly renewable energy source.
- ➢ Reduces electricity bills-since you will be meeting some of your energy needs with the electricity your solar system has generated, your energy bills will drop.
- ➢ Diverse applications- You can generate electricity or heat. Solar energy can be used to produce

electricity in areas without access to the energy grid, to distill water in regions with limited clean water supplies and to power satellites in space.

- Low maintenance costs
- Technology in the solar power industry is constantly advancing and improvements will intensify in the future

40.List any four disadvantages of solar energy.

- Cost- The initial cost of purchasing a solar system is fairly high.
- Weather dependent- although solar energy can still be collected during cloudy and rainy days, the efficiency of the solar system drops.
- Solar energy storage is expensive.
- Uses a lot of Space.
- Associated with pollution

41.What are instrument used to measure solar radiation?

Measurement of solar radiation is very important because of the increasing number of solar heating and cooling applications, and the need for accurate solar irradiations data to predict performance. They are

- Pyrheliometer-It is used to measure direct solar radiation from the sun and its marginal periphery
- Pyranometer-the sensor is located at the base of a tube whose axis is aligned with the direction of sun rays.

42.Define solar Insolation.

The power per unit area produced by the Sun in the form of electromagnetic radiation. Irradiance may be measured in space or at the Earth's surface after atmospheric absorption and scattering. Total solar irradiance (TSI), is a measure of the solar radioactive power per unit area normal to the rays, incident on the Earth's upper atmosphere. The solar constant is a conventional measure of mean TSI at a distance of one Astronomical Unit. Irradiance is a function of distance from the Sun, the solar cycle, and cross-cycle changes. Irradiance on Earth is most intense at points directly facing (normal to) the Sun.

43.Write some in industrial applications of solar energy.

- Industrial loads are mostly on continuous basis throughout the year.
- Industrial plants have maintenance crew, or in small plants skilled people, who can attend to smooth operation of solar system.
- Total quantum of energy replaced by solar is significantly more causing higher reduction in oil imports

44.Justify the use of solar energy.

Solar energy are used in the following instances:

In remote areas utility power lines are costly to extend provide backup power during utility outages

- Minor glitch backup might be only for two minutes
- Hurricane line damage may need two weeks to repair
- Cleaner energy with no CO_2 emissions
- Self-satisfaction of using some “free” energy (but it costs money to get it)

45. What do you know about solar radiation at the earth’s surface?

From the point of view of utilization of solar energy we are more interested in the energy received at the earth’s surface than in the extra-terrestrial energy. Solar radiation received at the surface of the earth is entirely different due to the various reasons. Of the total light removed from the direct solar beam by scattering in the atmosphere (approximately 25% of the incident radiation when the sun is high in the sky, depending on the amount of dust and haze in the atmosphere), about two-thirds ultimately reaches the earth as diffuse sky radiation.

46. What is beam radiation?

Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called direct radiation or beam radiation.

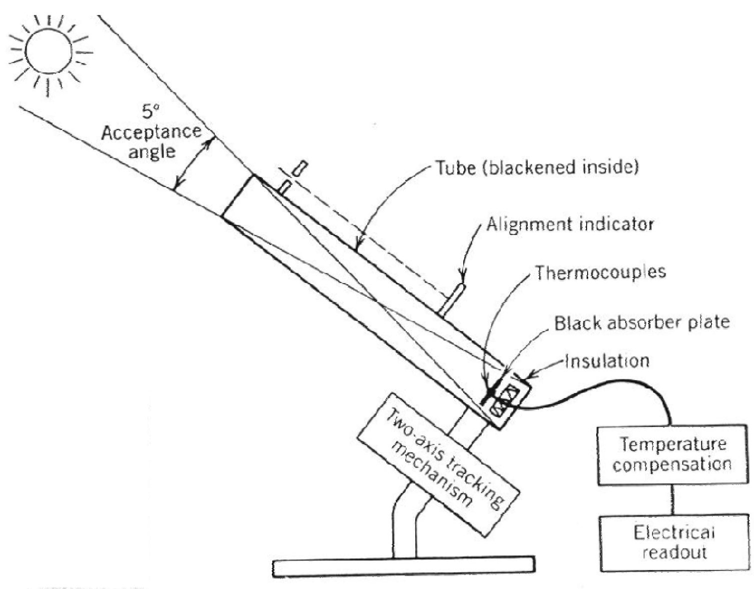
Solar thermal power can only use direct sunlight, called ‘beam radiation’ or Direct Normal Irradiation(DNI), i.e. that fraction of sunlight which is not deviated by clouds, fumes or dust in the atmosphere and that reaches the earth’s surface in parallel beams for concentration. Hence, it must be sited in regions with high direct solar radiation. Suitable sites should receive at least 2,000 kilowatt hours (kWh) of sunlight radiation per m^2 annually, whilst best site locations receive more than 2,800kWh/m^2/year.

47. Define diffuse radiation.

Diffuse radiation is that solar radiation received from the sun after its direction has been changed by reflecting and scattered by atmosphere. Because of the solar radiation is scattered in all direction in the atmosphere, diffuse radiation comes to the earth from all parts of the sky. Diffuse sky radiation is solar radiation reaching the Earth's surface after having been scattered from the direct solar beam by molecules or suspensions in the atmosphere.

48. What is purpose of using pyreheliometer?

A pyrheliometer is an instrument which measures beam radiation. In contrast to a pyranometer, the sensor is located at the base of a tube whose axis is aligned with the direction of sun rays. Thus diffuse radiation is essentially blocked from the sensor surface. A pyrheliometer is used to measure direct solar radiation from the sun and its marginal periphery. To measure direct solar radiation correctly, its receiving surface must be arranged to be normal to the solar direction. For this reason, the instrument is usually mounted on a sun-tracking device called an equatorial mount.



Pyreheliometer

49. Describe the classifications of air heaters.

- The first type has a non-porous absorber in which the air stream does not flow through the absorber plate. Air may flow above and or behind the absorber plate.
- The second type has a porous absorber that includes slit and expanded metal, transpired honeycomb and over-lapped glass plate absorber.
- Unglazed air collectors and transpired solar collectors

50.List the applications of solar air heaters.

- Heating building
- Drying agricultural produce and lumber
- Heating green houses
- Air conditioning building utilizing desiccant beds or a absorption refrigeration process
- Using air heaters as the heat source for a heat engine such as brayton and stirling cycles Measurement of solar radiation and collectors

51. Write the process of producing distilled water from sea water by using solar energy.

Solar desalination is a technique to desalinate water using solar energy. There are two basic methods of achieving desalination using this technique; direct and indirect. They include but are not limited to Multiple Effect Humidification (MEH), Multiple Stage Flash Distillation (MSF), Multiple Effect Distillation (MED), Multiple Effect Boiling (MEB), Humidification Dehumidification (HDH), Reverse Osmosis (RO), and Freeze effect distillation.

Indirect solar desalination systems using photovoltaic (PV) panels and reverse osmosis (RO) have been commercially available.

52. What are the methods used for solar fuel production?

Solar fuel technologies convert solar energy into chemical fuels such as hydrogen, synthetic gas and liquids such as methanol and diesel. The three basic routes to solar fuels, which can work alone or in combination, are:

- Electrochemical
- photochemical/photo-biological and
- Thermo-chemical.

53. Explain the process of solar thermal production in India

Active solar heating and cooling technologies for residential and commercial buildings represent armature market. This market, which is distributed to various degrees in most countries of the world, grew by 34.9% from 2007 to 2009 and continues to grow at a rate of about 16% per year. At the end of 2009, the global installed capacity of thermal power from these devices was estimated to be 180GWth.The global market for sales of active solar thermal systems reached an estimated 29.1 GW^{th} in 2008 and 31 GW^{th} in 2009.

54. List the advantages and disadvantages of solar power.

Advantages: Reflecting surfaces required less material hence cost of material is low. The absorber area of a concentrator system is smaller than that of a flat type. Little or no anti-freeze is required.
Disadvantages: High initial cost, Non-uniform flux on the absorber. Additional optical losses such as Reflectance loss and the intercept loss.

55. Mention a few applications of solar energy.

Three broad categories of possible large scale applications of solar power are:

- The heating and cooling of residential and commercial buildings;
- The chemical and biological conversion of organic material to liquid, solid and gaseous fuels;
- Conversion of solar energy to electricity.

56.List few applications of low temperature water heaters in domestic and industrial use. (Nov/Dec 2021)

- **Domestic use:** In domestic sector, hot water is used for bathing, washing of clothes & utensils etc.
- **Industrial use:** Process Industries, Preheating boiler feed water.

Solar thermal applications

57. What are the applications solar thermal?

Solar thermal energy can be used for such applications as, space heating, air conditioning, ater, industrial process heat, drying, distillation and desalination, and electrical power.

Solar thermal energy storage

58. What is Solar thermal energy storage?

Solar thermal storage (STS) refers to the accumulation of energy collected by a given solar fiel for its later use. STS technologies are installed to provide the solar plant with partial or full dispatch ability

59. What are the types of Solar thermal energy storage

There are three types of TES considering the process of storage and the corresponding medium: sensible energy storage; latent energy storage; and. thermo chemical storage.

Fundamentals of solar photo voltaic conversion- Solar cells

60. what are the three principal solar energy conversion processes?

Main types of sunlight conversion

- conversion to electricity (photovoltaic effect);
- conversion to usable heat (for example, via thermal collectors);
- conversion to matter / fuel (for example, production of biomass through photosynthesis).

61. What are the disadvantages of solar energy conversion?

1. It is costly
2. It requires energy storage
3. It needs no insolation at night.

62. What is meant by solar photo voltaic?

The direct conversion of solar energy into electrical energy by means of the photovoltaic effect, that is, the conversion of light (or other electromagnetic radiation) into electricity. The photovoltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation.

63. List the application of solar PV system.

Water pumping sets for micro irrigation and drinking water supply

- Radio beacons for ship navigation at ports
- Community radio and television sets
- Cathodic protection of oil pipe lines
- Weather monitoring
- Railway signaling equipment
- Battery charging
- Street lighting

64. What are the advantages & disadvantages of PV solar energy conversion system?

Advantages

- Direct room temperature conversion of light to electricity through a simple solid state device.
- Absence of moving parts
- Maintenance cost is low s they are easy to operate
- Do not create pollution
- Long effective life
- Highly reliable

Disadvantages

- High cost
- In many applications energy storage is required because of no insolation at night.

65. What are the components of photo-voltaic system?

- 1. Solar cell array.
- 2. Load leveler.
- 3. Storage system.
- 4. Tracking system.

66. What are the different types of solar photo voltaic arrays?

- 1. Flat-plate Arrays.
- 2. Concentrating Arrays.

67. Define Concentration ratio.

$$\text{Concentration ratio (CR)} = \frac{\text{kW/m}^2 \text{ in solar radiation on surface}}{\text{kW/m}^2 \text{ on surface of focus of collector}}$$

68. What is the efficiency of a solar cell?

$$\text{Efficiency of a solar cell} = \frac{\text{Electrical power output}}{\text{Power intercepted}}$$

69. Briefly explain the working of solar photovoltaic cell. **(Nov/Dec 2021)**

A photovoltaic (PV) cell, also known as a solar cell, is an electronic component that generates electricity when exposed to photons, or particles of light. This conversion is called the photovoltaic effect

70.Define photovoltaic system.

A photovoltaic system, also PV system or solar power system, is a power system designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, as well as mounting, cabling, and other electrical accessories to set up a working system.

Part-B

Solar radiation

1. Write briefly about Physical Principles of the Conversion of Solar Radiation into Heat.

The fundamental process now in general use for heat conversion is the *green house effect.* The name come from its first use in green houses, in which it is possible to grow exotic plants in cold climates through better utilization of the available sunlight. Most of the energy we receive from the sun comes in the form of light, a shortwave radiation, not all of which is visible to the human eye. When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy; the material becomes warm and stores the heat, conducts it to surrounding materials (air water, other solids or liquids) or reradiates it to other materials of lower temperature. This radiation is a long wave radiation.

Fig.2.1 shows how temperature on earth is affected by the 'green house effect'. Visible sunlight is absorbed on the ground, at a temperature of 20°C, for example emits infra-red light at a wavelength of about 10 μm, but CO_2 in atmosphere absorbs light of that wavelength and back radiates part of it to earth. ($C0_2$ does not absorbs the incoming sunlight which has a shorter wavelength). Hence the green house effect brings about an accumulation of energy of the ground.

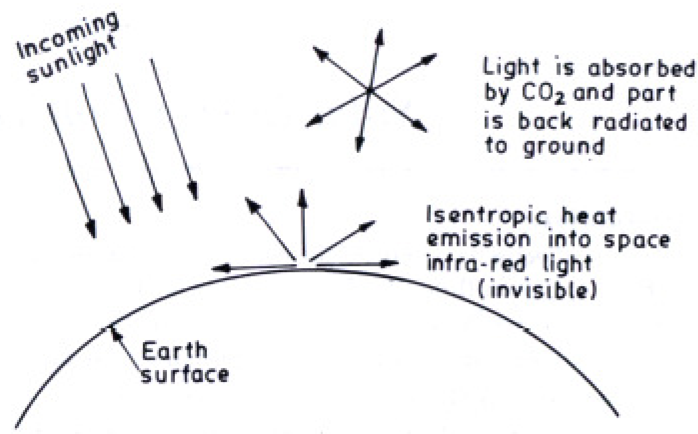


Fig 2.1 The green house effect radiated to the CO_2 Content of the atmosphere.

Glass easily transmits short-wave radiation, which means that it poses little interference to incoming solar energy, but it is a very poor transmitter of long-wave radiation. Once the sun's energy has passed through the glass windows and has been absorbed by some material side, the heat will not be reradiated back outside. Glass therefore, act as a heat trap, a phenomenon which has been recognized for sometime in the construction of green houses, which can get quite warm on sunny days, even in the middle of winter; this has come to be known in fact, as the 'green house effect'. Solar collectors for' home heating usually called ***flat plate collectors,*** almost have one or more glass *covers,* although various plastic and other transparent materials are often used instead of glass.

In Fig. 2.2. a black-painted plate absorbs the incoming sunlight. About it, is fixed a plate of ordinary window glass. When the temperature of the black plate increases, its emits an increment of thermal heat in the form of infra-red light. The black absorber has the properties of a black body; ideal black bodies have not only the highest absorption rate but also the highest emission coefficient for all wavelengths of light. Emission increases with temperature, following T^4 law. The re-emitted light if so progressively shorter wavelength and greater energy as the temperature of the black body increases. This is expressed by Wien's law, which may be written as :

$$\lambda_{max} .T = \text{constant} = 2989 \ \mu m \ \text{Kelvin}$$

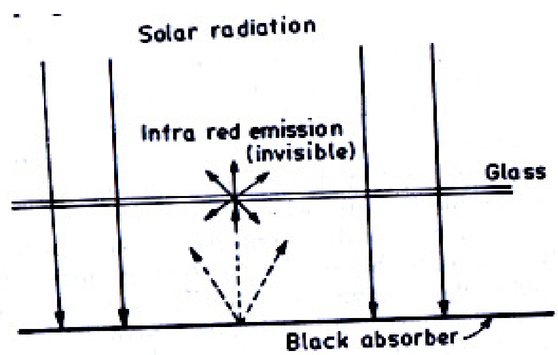


Fig 2.2 Principle of green house effect

T being the surface temperature of the black body and the wavelength λ_{max} at which light emission reaches a maximum. Some examples are given in Fig. 2.3.

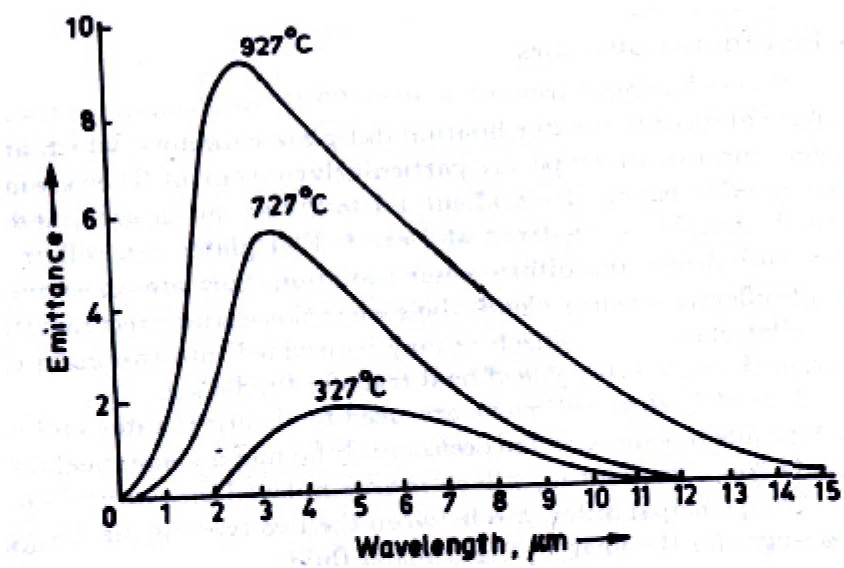


Fig.2.3 Emittance of black body at different temperatures.

The sun emits radiation like a "black body" whose surface temperature is about 5700°C, this corresponds to maximum emission of 0.5 µm. A black body at a room temperature emits radiation with a maximum at about 10 urn, which is within the spectrum of invisible of infra-red light. The ordinary glass plate fixed above the black plate in a green house has a spectral absorption which can be seen in Fig.2.3. The profile of plastic is similar. Thus glass which is relatively transparent for visible light is absorbent for the infra-red light emitted by the black plate when it evacuates its thermal energy.

The infra-red light absorbed by the glass is remitted in all directions, half of it is emitted to the outside and lost, the other half re-emitted towards the black plate which absorbs it again. More and more heat is accumulated in the way in the black plate, whose temperature thus increases. Equilibrium is reached when the energy gain by absorption of visible light is exactly balanced by the loss of energy through infra-red emission of the glass plate. With rising temperature, the wavelength of the infra-red emission becomes shorter. At 200°C (473°K) the maximum radiation is emitted at about 6 μm, compared with 10 μm at room temperature. Finally at about 500°C (773°K) the bulk of the radiation would be emitted at 4 μm, at which wavelength, glass is partially transparent for infra-red light.

It follows that an efficient green house effect is possible only below 500°C. However, unless concentration of sunlight is combined with the green house effect, the equilibrium temperature achieved are much lower because, practice, the equilibrium temperature is further reduced by heat losses from the black plate due to thermal conductivity and air convection

Solar Radiation Measurements techniques

2. What are the various Solar Radiation Measurements techniques available?

Measurements of solar radiation are important because of the increasing number of solar heating and cooling applications, and the need for accurate solar irradiation data to predict performance. Experimental determination of the energy transferred to a surface by solar radiation required instruments which will measure the heating effect of direct solar radiation and diffuse solar radiation. Measurements are also made of beam radiation, which respond to solar radiation received from a very small portion of the circum solar sky. A total radiation type of instrument may be used for measuring diffuse radiation alone by shading the sensing element from the sun's direct rays:

Two basic types of instruments are employed for solar radiation measurement:

(1) **Pyrheliometer,** which collimates the radiation to determine the beam intensity as a function of incident angle, and
(2) **Pyranometer,** which measures the total hemispherical solar radiation. The pyranometer measurements are the most common.

The total solar radiation arriving at the outer edge of the atmosphere is called the solar constant as already mentioned.

(A) Pyrheliometers:

A pyrheliometer is an instrument which measures beam radiation. In contrast to a pyranometer, the sensor disc is located at the base of a tube whose axis is aligned with the direction of the sun's rays. Thus diffuse radiation is essentially blocked from the sensor surface.

Most pyrheliometers used for routine measurements operate on the thermopile effect and are similar to pyranometer in this respect. They differ in that mechanically they must follow the sun to measure only direct sunlight and avoid the diffuse component. In practice, direct solar radiation is measured by attaching the instrument to an electrically driven equatorial mount for tracking the sun. The diffuse cumponent is avoided by installing a collimator tube over the sensor with a circular cone angle of about 5°.

Problems with pyrheliometer measurements are several fold ; the aperture angle, the circum solar contributions and imprecision in the tracking mechanism. The first two problems are almost impossible to eliminate because of the inability to define the solar disk precisely and the finite dimensions of the instrument components. The practical matter of precise taking and sensor orientation are simply great. The use of correction factors in not only involved but somewhat unreliable.

The direct solar component on a horizontal surface may also be obtained using a shading ring, this is done by subtracting the shaded (diffuse) from the unshaded (global) reading.

Current practice in solar radiometry relies primarily on thermoelectric transducers. However, relatively low cost photovoltaic transducers are becoming more popular. To measure the direct solar radiation, the receiving surface must be normal to direct solar rays, i.e. a line joining the sun and receiver. Three pyrheliometers have been in wide-spread use to measure normal incident beam radiation:

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

The instruments provide primary and secondary standard of solar radiation measurements.

(i) Angstrom compensation Pyrheliometer:

In this pyrheliometer, a thin blackened shaded managing strip (Size 20 x 2 x 0.1 mm) is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation. It is shown schematically in Fig. 2.4 Under steady state conditions (both strips at identical temperature) the energy used for heating is equal to the absorbed solar energy.

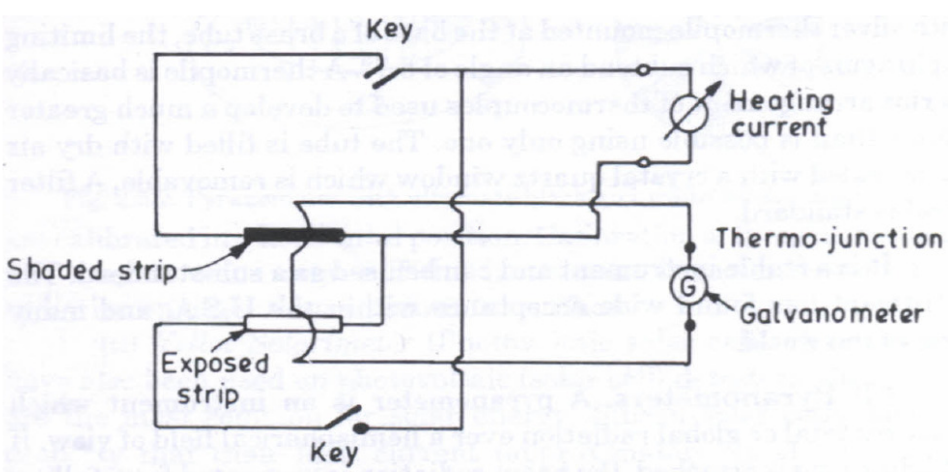


Fig.2.4. Electric circuit for Angstrom Pyrheliometer.

The thermocouples on the back of each strip, connected in opposition through a sensitive galvanometer (or other null detector), are used to test for the equality of temperature. The energy H of direct radiation is calculated by means of the formula,

$H_{DN} = Ki^2$

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

i = heating current in amperes

K is a dimension and instrument constant

$= \frac{R}{W\alpha}$

where R is the resistance per unit length of the absorbing strip (Ω/cm).

W is the mean width of the absorbing strip, and

α is the absorbing coefficient of the absorbing strip.

(ii) Abbot silver disk Pyrheliometer:

It consists essentially of a blackened silver disk positioned at the lower end of a tube with diaphragms to limit the whole aperture to 5.7°. A mercury in glass thermometer is used to measure the temperature at the disk. A shutter made of three polished metal leaves is provided at the upper end of the tube to allow solar radiation to fall on the disk at regular intervals is shown in fig.2.5 and the corresponding changes in temperature of the disk are measured.

The thermometer stem is bent through 90° so that it lies along the tube to minimize its exposure to the sun. The instrument must of course be calibrated against a primary standard, but their stability has been found to be very good and they are widely used for calibrating pyranometers.

S – Shutter, C – collimating tube, T – Thermometer, D – Blackend silver disk, B – Insulated base.

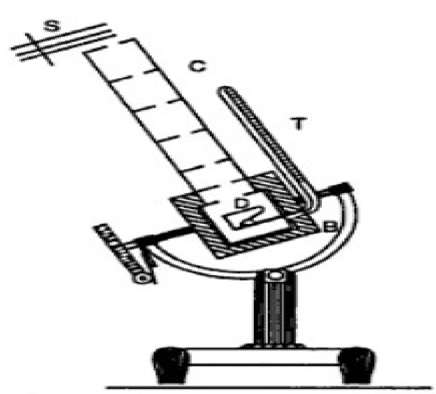


Fig.2.5 Abbot's silver disc pyrheliometer.

(iii) Eppley Pyrheliometer:

The sensitive element in an Eppley pyrheliometer is a temperature compensated 15 junction bismuth silver thermopile mounted at the base of a brass tube, the limiting diaphragms of which subtend an angle of 5.7°. A thermopile is basically a series arrangement of thermocouples used to develop a much greater voltage than is possible using only one. The tube is filled with dry air and is sealed with a crystal quartz window which is removable. A filter wheel is standard.

It is a stable instrument and can be used as a sub-standard. The instrument has found wide acceptance within the U.S.A and many parts of the world.

(B) Pyranometers:

A pyranometer is an instrument which measures total or global radiation over a hemispherical field of view. If a shading ring is attached, the beam radiation is prevented from falling on the instrument sensor and in then measures only the diffuse component of the radiation. In most pyranometers, the sun's radiation is allowed to fall on a black surface to which the hot junctions of a thermopile are attached. The cold junctions of the thermopile are located in such a way that they do not receive the radiation. As a result, an e.m.f. proportional to the solar radiation is generated. This e.m.f. which is usually in the range of 0 to 10 mV can be read, recorded or integrated over a period of time with regular calibration of about ± 2 percent can be obtained.

There are following types of pyranometers :

(i) Eppley pyranometer,
(ii) Yellot solarimeter (photo-voltaic solarcell),
(iii) Moll-Gorczyheski solarimeter,
(iv) Bimetallic Actionographs of the Rabitzsch type,
(v) Velochme pyranometer,
(vi) Thermo electric pyranometer etc.

Eppley pyranometer:

It is based on the principle as stated above that there is a difference between the temperature of black surfaces (which absorb most solar radiation) and white surfaces (which reflect most solar radiation). The detection of temperature difference is achieved by thermopile. It uses concentric silver rings 0.25 mm thick, appropriate coated black and white, with either 10 or 50 thermocouple junctions to detect temperature differences between coated rings. Later models use wedges arranged in a circular pattern, with alternate black and white coatings. The disks or wedges are enclosed in a hemispherical glasscover. Similar instruments are manufactured in Europe under the name Kipp. The Eppley pyranometers, and similar instruments are calibrated in a horizontal position.

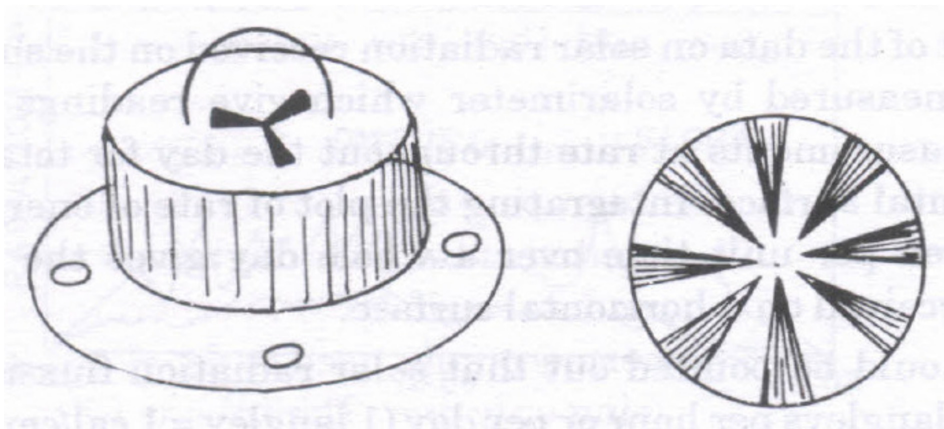


Fig. 2.6 Pyranometer with alternate black and white sensor segments.

Calibration of these instruments will vary to some degree if the instrument is inclined to measure radiation on other than a horizontal surface.

Yellot Solarimeter (Photovoltaic solar cell):

Pyranometers have also been used on photovoltaic (solar cell) detectors. Silicon cells are the most common for solar energy. Silicon solar cells have the property that their light current (approximately equal to the short circuit current at normal radiation levels) in a linear function of the incident solar radiation. They have the disadvantages that the spectral response is not linear, so instrument calibration is a function of the spectral distribution of the incident radiation.

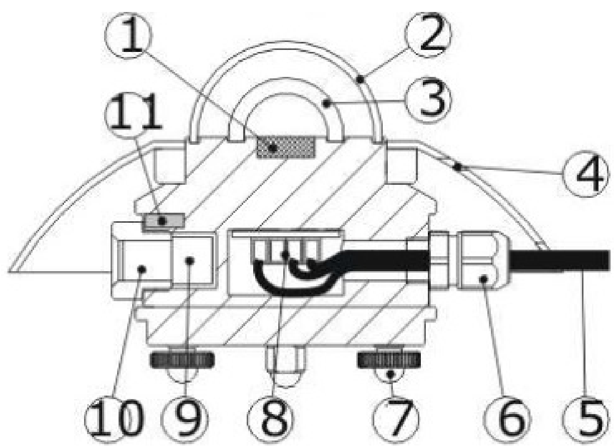


Fig 2.6 (1) sensor,(2,3) glass domes, (5) cable, standard length 5m,(9)desiccant

Thermoelectric pyranometer:

Thermoelectric pyranometer is shown in Figure.2.7 The instrument's radiation-sensing element has basically the same structure as that of a thermoelectric pyrheliometer. Another similarity is that the temperature difference derived between the radiation-sensing element (the hot junction) and the reflecting surface (the cold junction) that serves as a temperature reference point is expressed by a thermopile as thermo electromotive force. In the case of a pyranometer, methods of ascertaining the temperature difference are as follows:

1) Several pairs of thermocouples are connected in series to make a thermopile that detects the temperature difference between the black and white radiation-sensing surfaces.
2) The temperature difference between two black radiation-sensing surfaces with differing areas is detected by a thermopile.
3) The temperature difference between a radiation-sensing surface painted solid black and a metallic block with high heat capacity is detected by a thermopile.

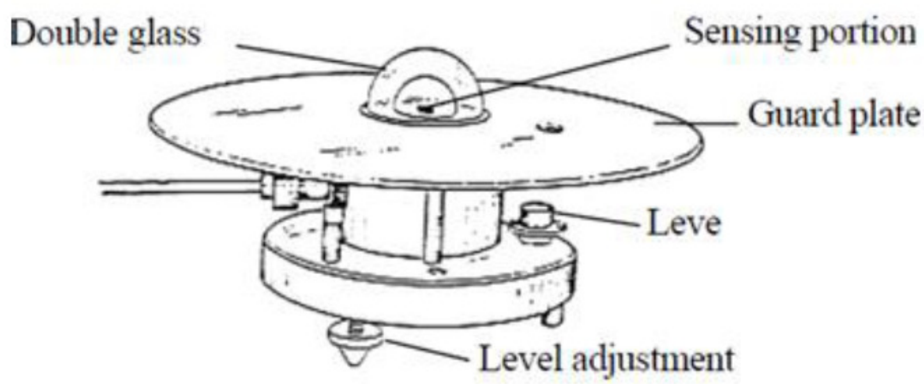


Fig.2.7. Thermoelectric pyranometer

Sunshine Recorder

3. Give short notes on Sunshine Recorder.

The duration of bright sunshine in a day is measured by means of a sunshine recorder is shown in fig.2.8. The sun's rays are focused by a glass-sphere to point on a card strip held in a groove 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 days the sun moves across the sky, the image moves along the strip. Thus a burnt space whose length is proportional to the duration of sun shine is obtained on the strip.

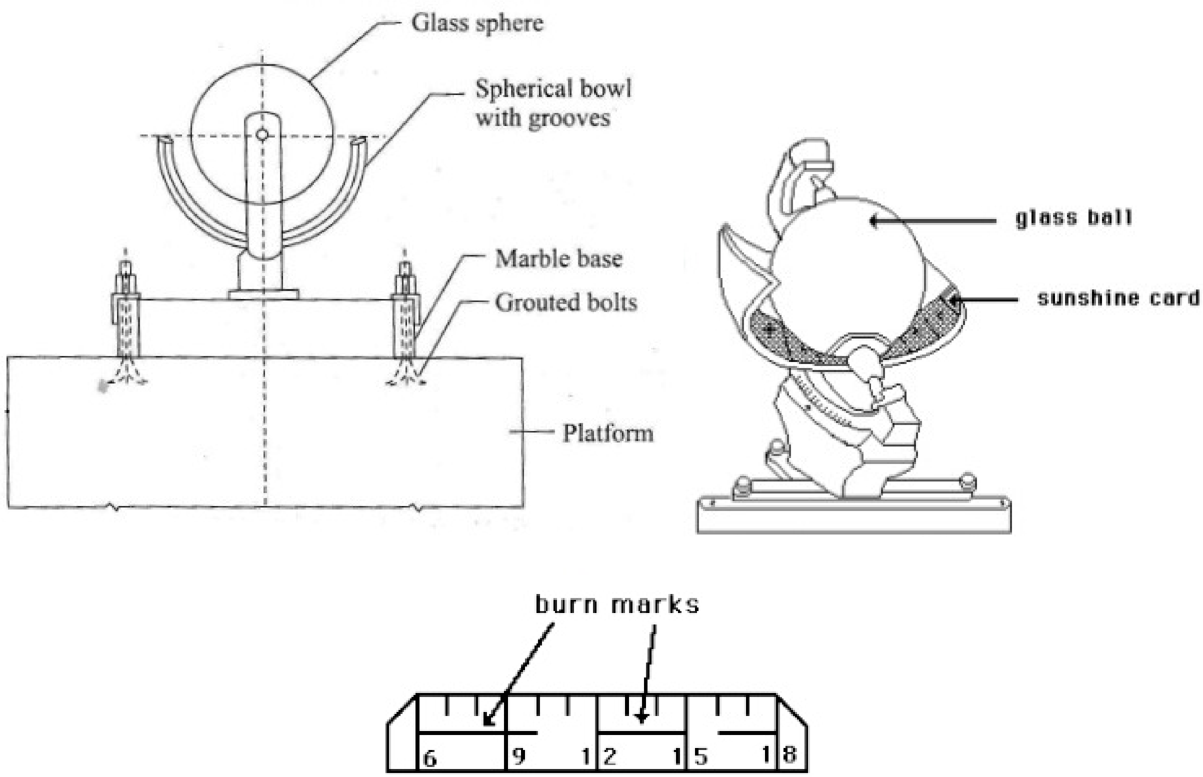


Fig.2.8.Sun Shine Recorder.

<u>Solar Radiation Data</u>

4. Explain about the Solar Radiation Data. (or) Evaluate the methods to use the solar data for solar energy generation forecasting. (Nov/Dec 2020)

Solar radiation data are available in several forms and should include the following informations.

1. Wheather they are instantaneous measurement or values integrated over some period of time (usually hour or day).
2. The time or time period of the measurements.
3. Whether the measurements are of beam, diffuse or total radiation, and the instrument used.
4. The receiving surface orientation (usually horizontal, it may be inclined at a fixed slope or normal).
5. If averaged, the period over which they are averaged (e.g., monthly average of daily radiation).

Most of the data on solar radiation received on the surface of the earth are measured by solarimeter which give readings for instantaneous measurements at rate throughout the day for total radiation on a horizontal surface. Integrating the plot of rate of energy received per unit area per unit time over a whole day gives the langleys of radiation received on a horizontal surface.

It should be pointed out that solar radiation flux is generally reported in langleys per hour or per day (1 langley = 1 cal/cm^2). The unit 'langley' has been adopted in honour of Samuel Langley who made the first measurement of the spectral distribution of the sun.

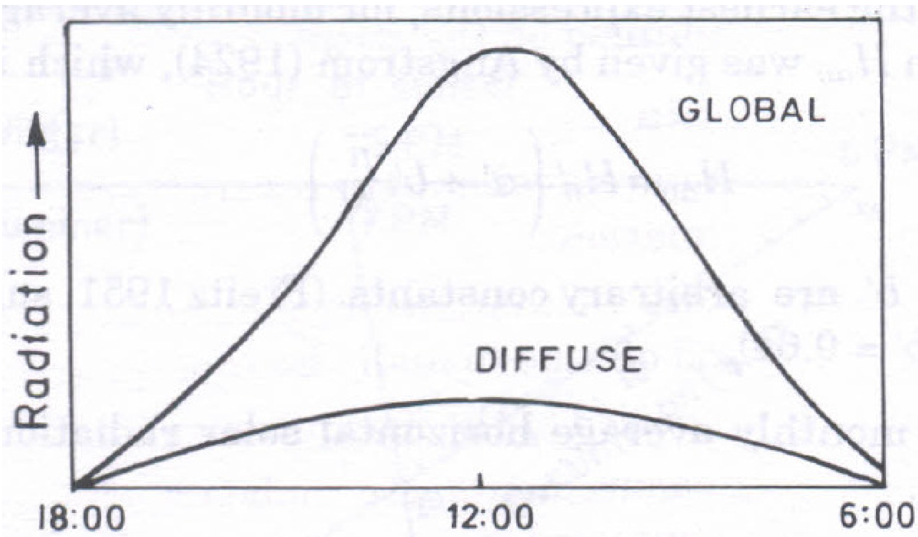


Fig. 2.9. A typical daily record of global and diffuse radiation.

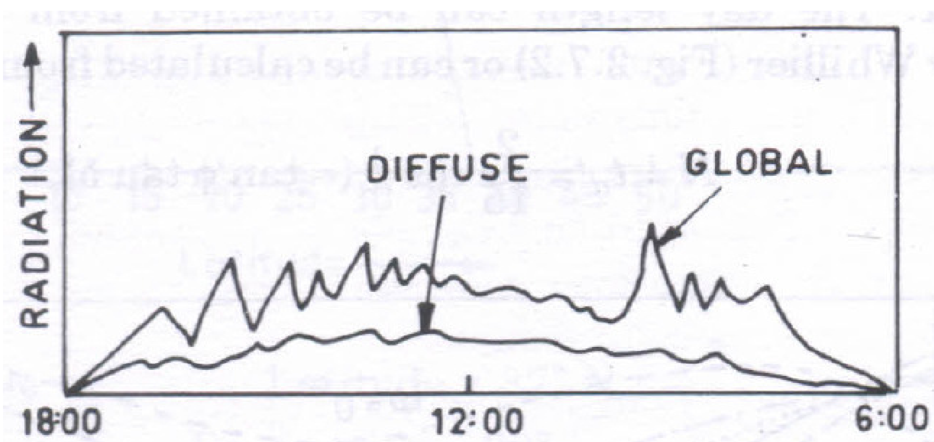


Fig. 2.10. A typical global and diffuse radiation on a cloudy day.

For instance, the total daily solar radiation received in Calcutta (latitude 20° 32' N) on the basis of yearly average is 680 langleys (i.e., 680 cals/cm^2/day).

Average solar radiation data are also available from maps. Maps can be used as a source of average radiation if data are not available. Charts are also available for clear day horizontal radiation for any period for any latitude. Tables are also available for hours of sun shine for various locations.

Maps have been drawn by Mani and Chacko for India. They show the distribution of the average daily global radiation, and the average daily diffuse radiation. A typical daily record of the global and diffuse radiation measured on a clear day is shown in Fig. 2.9. In contrast to the smooth variation shown in the Fig. 2.9, a jagged variation with many peaks is obtained on a cloudy or a partly cloudy day. This is shown in Fig 2.10. A solar designer is primarily interested in average values of radiacion for locations. The averaging is usually made over a month and tabulations showing the hourly variation of global and diffuse radiation, the amount received per day and the sunshine hours per day are prepared.

India lies between latitude 7° and 37° N, and receives an annual average intensity of solar radiation between 16700-29260 kJ/m^2/day, (400-700 cal/cm^2/day). The daily solar insolation figures over the different places in India accurately available. Peak values are generally measured in April or May, with parts of Rajasthan and Gujarat receiving over 25100 kJ/m^2/day (600 cal/cm^2/day). During the monsoon and winter months the daily solar radiation decreases to about 16700 kJ/m^2/day (400 cal/cm^2/day).

The annual daily diffuse radiation received over the whole country is observed to be about 7300 kJ/m^2/day (175 cal/cm^2/day). The minimum values of diffuse radiation, measured over many parts of the country during November and December, are between 3135 – 4180 kJ/m^2 day, (75 and 100 cal/cm^2/day) while maximum values measured over the whole country are about 12550 kJ/m^2/day (300 cal/cm^2/day) specially in July in Gujarat

<u>Solar thermal collectors – Flat plate and concentrating collectors</u>

5. Give brief Introduction to Solar Energy Collector.

A solar collector is a device for collecting solar radiation and transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. These are general of two types :
(i) Non concentrating or flat plate type solar collector.
(ii) Concentrating (focusing) type solar collector.

The solar energy collector, with its associated absorber, is the essential component of any system for the conversion of solar radiation energy into more usable form *(e.g.* heat or electricity). In the non-concentration type, the collector area *(i.e.* the area that intercepts the solar radiation) is the same as the absorber area *(i.e.* the area absorbing the radiation). On the other hand, in concentrating collectors, the area intercepting the solar radiation is greater, sometimes hundred of times greater than the absorber area.

By means of concentrating collectors, much higher temperatures can be obtained than with the non-concentrating type. Concentrating collectors may be used to generate medium pressure steam. They use many different arrangements of mirrors and lenses to concentrate the sun's rays on the boiler. This type shows better efficiency than the flat plate type. For best efficiency, collectors should be mounted to face the sun as it moves through the sky.

6. Explain briefly about Flat-Plate Collectors and its types. (or) Describe the characteristics and types of flat plate solar collectors (Nov/Dec 2020)

Where temperatures below about 90°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 sq. m, in area, and are relatively simple to construct and erect. Flat plates can collect and absorb both direct and diffuse solar radiation, they are consequently partially effective even on cloudy days when there is no direct radiation.
Flat-plate solar collectors may be divided into two main classifications based on the type of heat transfer fluid used.

° ***Liquid heating collectors*** are used for heating water and nonfreezing aqueous solutions and occasionally for non-aqueous heat transfer fluids. Air or gas heating collectors are employed as ***solar air heaters***.

The principal difference between the two types is the design of the passages for the heat for the transfer fluid.

The majority of the flat-plate collector have five main components as follows:

(i) A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet.

(ii) Tubes, fins, passages or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.

(iii) The absorber plate, normally metallic or with a black, surface, although a wide variety of other materials can be used with air heaters.

(iv) Insulation, which should be provided at the back and sides to minimise the heat losses. Standard insulating materials such as fibre glass or styro-foam are used for this purpose.

(e) The casing or container which enclose the other components and protects them from the weather.

(A)A Typical Liquid Collector

There are many flat-plate collector designs, but most are based on the principle shown in Fig. 2.11. It is the plate and tube type collector.

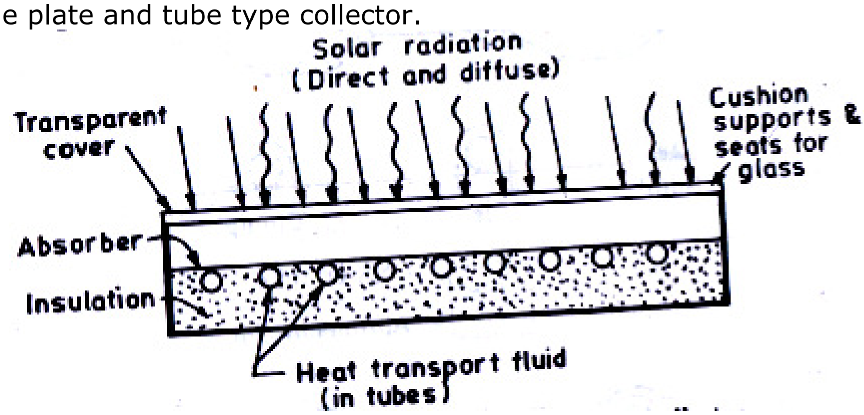


Fig 2.11 Selection through typical flat-plate collector.

It basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface. Typically a metal plate, usually of copper, steel or aluminium material with tubing of copper in thermal contact with the plates, are the most commonly used materials. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while the tubes, which are also of metal, range in diameter from 1 to 1.5 cm. They are soldered, brazed or clamped to the bottom (in some cases, to the top) of the absorber plate with the pitch ranging from 5 to 15 cm. In some designs, the tubes are also in line and integral with the absorber plate. For the absorber plate corrugated galvanized sheet is a material widely available throughout the world, Fig. 2.12 *(a)* and *(b)* show two ways in which it has been used.

The use of conventional standard panel radiators shown in Fig. 2.12 *(c)* is one of the simplest practical applications. The methods of bonding and clamping tubes to flat or corrugated sheet are shown in Fig. 2.12 *(d)* and *(e),* while Fig. 2.12 *(f)* is the "tube in strip" or roll bond design, in which the tubes are formed in the sheet, ensuring a good thermal bond between the sheet and the tube.

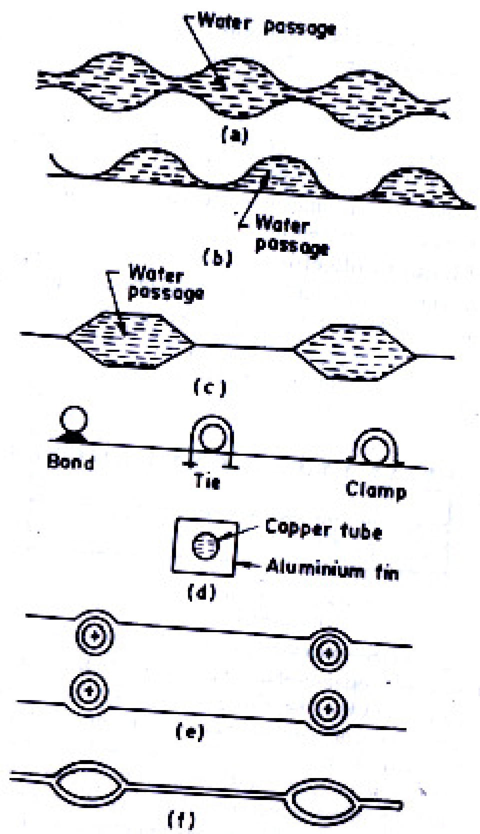


Fig 2.12 Cross-section through collector plates

Heat is transferred from the absorber plate to a point of Use by circulation of fluid (usually water) across the solar heated surface. ***Thermal insulation*** of 5 to 10 cm thickness is Usually placed behind the absorber plate to prevent the heat losses from the rear surface. Insulation materials is generally mineral wool or glass wool or fiber glass as stated above.

The front covers are generally glass (may be one or more) that is transparent to in-coming solar radiation and opaque to the infra-red re-radiation from the absorber. The glass covers act as a convection shield to reduce the losses from the absorber plate beneath. Glass is generally used for the transparent covers but certain plastic films may be satisfactory. Glass is the most favourable material. Thickness of 3 and 4mm are commonly used. The usual practice is to have 1 or 2 covers with a specific ranging from 1.5 to 3 cm.

7.Write briefly about Advantages of Flat plate Collectors

Advantages of second glass which is added above the first one are:

(i) Losses due to air convection are further reduced. This is important in windy areas.

(ii) Radiation losses in the infra-red spectrum are reduced by a further 25%, because half of the 50% which is emitted outwards from the first glass plate is back radiated. It is not worthwhile to use more than two glass plates. This is due to the fact that each plate reflects about 15% of the incoming sunlight.

As we know that main purpose of the transparent cover of the flat- plate collector is to decrease heat loss without significantly reducing the incoming solar radiation. In the first place, the relatively still (or stagnant) air space between the cover and the absorber plate largely prevents loss of heat from the plate by convection.

Furthermore, if the cover is made of glass, it permits the passage of solar radiations with wavelengths less than 2 micrometers (μm) but it is largely opaque to the longer wavelength thermal infra-red. As a result, heat is trapped in the air space between the cover and the absorber plate in a manner similar to green house. The effect is to reduce the loss of heat from the absorber. However, since the enclosed air is inevitably warmer than the ambient air, there is some loss of heat to the surroundings from the top of the cover by convection, conduction and radiation. The rate of heat loss increases as the temperature of the air space rises; as will be seen shortly, this affects the overall efficiency of the solar collector.

A certain proportion of the incident solar radiation is lost by absorption in the glass cover plates, but the loss can be kept small by using a clear ("water white'') glass with a low iron content. A much larger loss occurs as a result of partial reflection. Two glass plates may reflect some 15 per cent of the solar radiation coming from a perpendicular direction. The reflection loss increases as the direction of incidence departs from the perpendicular. The reflection of glass covers may be reduced by coating with thin films of certain substances *(e.g:* magnesium fluoride) or by gentle etching with a solution of hydrofluoric acid. Such antireflective coatings add to the cost of the collectors but make them more efficient.

Transparent plastics have been used in place of glass, but they have some drawbacks. Most plastics are not as opaque as glass to the thermal infra-red, radiation and so permit greater loss of heat from the absorber. They also suffer a decrease in transparency and sometimes breakup in the course of time due to heating and the action of solar ultraviolet radiation. Efforts are being made to develop better plastic materials that might be used in solar collectors.

For water streams the absorber plate can be any metal, plastic or rubber sheet that incorporates water channels, while for air systems the space above or below the collector plate serves as the conduit. The surface finish of the absorber plate may be a flat black paint with an appropriate primer. The primer coat should preferable be thin since a thick under coat of paint would increase the resistance to heat transfer. The primer should be of self etching type. If the primer is -not a self etching type, the repeated thermal expansion and contraction of the plate may cause the paint to peel after a year or so. Several types of backed on or chemical finishes are also available. Black painted absorbers are preferred because they are considerably cheaper. The coatings applied on absorber plate are called "selective coatings" which reduces the amount of energy emitted by thermal infra-red radiation. These are good absorbers of radiation below about 2 urns wavelength, but they are poor emitter for longer wavelengths. A promising selecting coating is ''black chrome" form of chromium sesquioxide (Cr_2 o_3) which embedded chromium metal, in a layer 0.15 to 2 μm thick, electrodeposited on a nickel base.

The liquid heated is generally water. However sometimes mixtures Of water and ethylene glycol are used, if ambient temperatures below 0°C are likely to be encountered.

Typical collector dimensions are 2 m x 1 m x 15 cm.

8. Express about the heat transport system used in liquid collectors.

Heat Transport System. The heat generated in the absorber is removed by continuous flow of a heat-transport (or heat transfer) medium, either water or air. It is mainly in the design of the heat transfer system that flat plate collectors differ. When water is used, it is most commonly passed through metal tubes with either circular or rectangular cross-section ; the tubes are welded to the absorber plate (or form integral part of it) so as to assure effective heat transfer of heat to the fluid. Some examples are already represented in Fig. 2.13. The tubes are connected to common headers at each end of the collector. In order to maximise the exposure to solar radiation, collectors are almost invariably sloped. Cooler water then enters at the bottom header, flows upward through the tubes where it is warmed by the absorber, and leaves by way of the top header. Fig. 2.13.

In one simple type of flat-plate collector, the absorber is a blackened sheet with close corrugations running from top to bottom. The water flows through the grooves formed by the corrugations. A problem with this design is that in cold weather, moisture may condense on the inside of the transparent cover plate and thus decrease the transmission of the solar radiation.

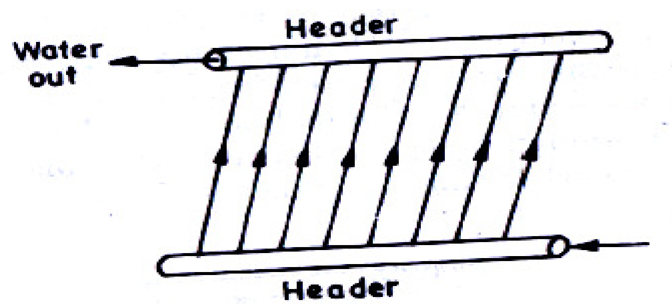


Fig 2.13 Water flow in flat-plate collector

Water is a very effective heat-transport medium, but it suffers from certain drawbacks, one is the possibility of freezing in the collector tubes in cold climates during cold nights. As stated earlier ethylene glycol is added to prevent freezing, but this generally adds to the complexity of the heating system. Furthermore, the antifreeze solution is less effective than water for heat removed from the absorber. In some cases, the water is drained from the collector tubes if freezing is expected, but difficulties have been experienced in refilling all the tubes in the morning.

Another problem arises from corrosion of the metal tubes by the water; this is aggravated if the water is drained at night thus allowing air to enter. The oxygen in air increases the rate of corrosion of most metals. Corrosion can be minimized by using copper tubing. Aluminium is a less expensive alternative, although periodic chemical treatment of water is desirable. Finally, leaks in a water (or anti freeze) circulation system require immediate attention.

9. Explain briefly about Typical Air Collectors or Solar Air Heaters in flat plate collector and also write the Classification of Air heaters.

(B) Typical Air Collectors or Solar Air Heaters.

Fig. 2.14 shows a schematic flat-plate collector where an air stream is heated by the back side of the collector plate. Fins attached to the plate increase the contact surface. The back side of the collector is heavily insulated with mineral wool or some other material. The most favourable orientation, of a collector, for heating only is facing due south at an inclination angle to the horizontal equal to the latitude plus 15^0.

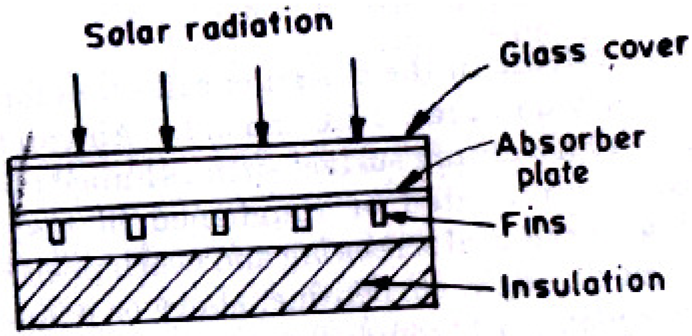


Fig 2.14. Typical Solar Air Collectors

Air has been used so far to a lesser extent as the heat-transport medium in solar collectors, but it may have some advantages over water. To decrease the power required to pump the necessary volume of air through tubes, wider flow channels are used. For example, the air may be passed through a space between the absorber plate and insulator with baffles arranged to provide a long (zig-zag) flow path Fig. 2.15.

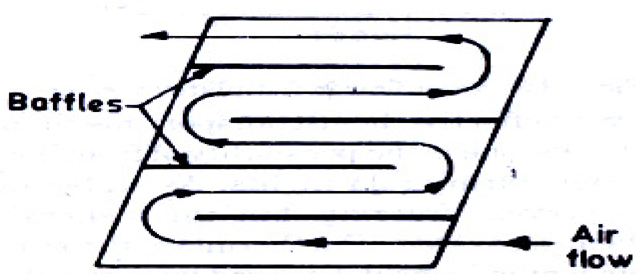


Fig.2.15 . Zig-zag air flow path in flat-plate collector

The use of air as the heat-transport fluid eliminates both freezing and corrosion problems, and small air leaks are of less concern than water leaks. Moreover, the heated air can be used directly (or by way of heat storage) for space heating. On the other hand, larger duct sizes and higher flow rates, with increased pumping power, are required for air than when water is the heat transport medium. Another drawback is that transfer of heat from air to water in a hot water supply system is inefficient.

But solar air heater has an important place among solar heat collectors. It can be used as subsystems in many systems meant for the utilization of solar energy. Possible applications of solar air heaters are drying or curing of agricultural products, space heating for comfort, regeneration of dehumidifying agents, seasoning of timber, curing of industrial products such as plastics.

Numerous variations in the design of collectors for heating air by solar energy are shown in Figs. 2.15. Air can be passed in contact with black solar absorbing surface such as finned plates or ducts as mentioned above, corrugated or roughened plates of various materials, several layer of metal screening and overlapped glass plates. Flow may be straight through, surpentine, above or below or on both sides of the absorber plate, or through a porous absorber material.

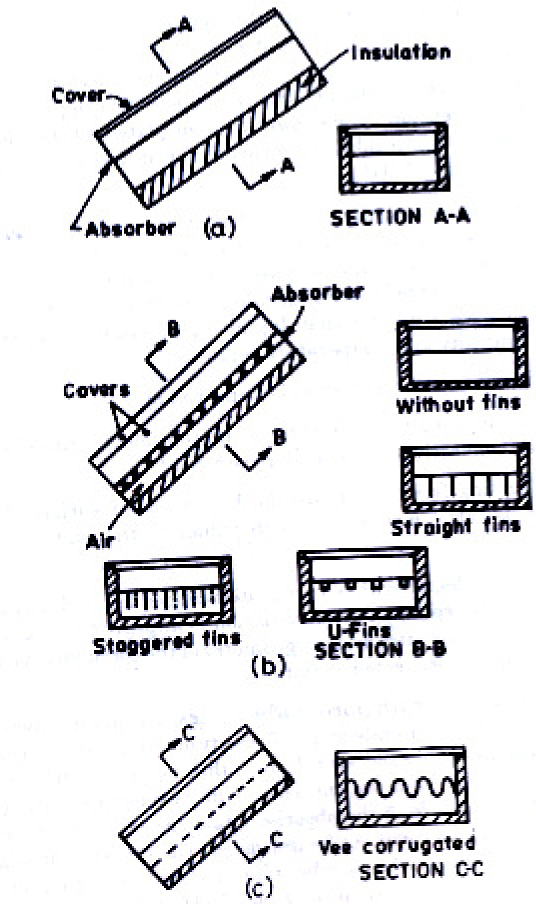


Fig. 2.15. Non-porous type air heaters.

Basically air heaters are classified in the following two categories.

(1) The first type has a non-porous absorber in which the air stream does not flow through the absorber plate. Air may flow above and or behind the absorber plate, as shown in Fig. 215.
(2) The second type has a porous absorber that includes slit and expanded metal, transpired honey comb and over-lapped glass plate absorber, as shown in Fig. 2.15.

(1) **Non-porous absorber plate type collectors.** A non-porous absorber May be cooled by the air stream flowing over both sides of the plate as shown in Fig. 2.15*(a).* In most common design

the air flows behind the absorbing surface. Air flow above the upper surface increases the convention losses from the cover plate and therefore is not recommended if the air inlet temperature rise at the collector are large, it is shown in Fig. 2.15*(b).*

Transmission of the solar radiation through the transparent cover system and its absorption is identical to that of a liquid type flat-plate collector. To improve collection efficiency selective coating may be applies provided there is no much cost. Due to low heat transfer rates, efficiencies are lower than liquid solar heaters under the same radiation intensity and temperature conditions.

Performance of air heaters is improved by :

(a) Roughning the rear of the plate to promote turbulence and improve the convective heat transfer coefficient, or

(b) Adding fins to increase the heat transfer surface. Usually turbulence is also increased which enhances the convective heat transfer.

A solar collector with V-corrugated copper foil is illustrated in Fig. 2.15*(c).* Absorption of solar radiation is improved due to surface radioactive characteristics and the geometry of the corrugations, which help in trapping the reflected radiation.

(2) Collectors with porous absorbers. The main drawback of the non-porous absorber plate is the necessity of absorbing all incoming radiation over the projected area from a thin layer over the surface, which is in the order of a few microns. Unless selective coatings are used, radiative losses from the absorber plate are excessive, therefore the collection efficiency cannot be improved. The pressure drop along the duct formed between the absorber plate and the rear insulation may also be prohibitive especially in the case of added fins to increase the heat transfer surface and turbulence rate. The difficulty with turbulence is the pressure drop across the collector. Too many surfaces and too much restriction to air flow will require a larger fan and a larger amount of energy to push the air through. The energy required for this cancels out saving from using solar energy, particularly if fan is electrical and it the amount of energy which is burned at the power plant to produce the electrical energy is included.

These defects are eliminated in a porous absorber type collectors in two ways.

(a) The solar radiation penetrates to greater depths and is absorbed gradually depending on the matrix density. The cool air stream introduced from the upper surface of the matrix is first heated by the upper layers which are cooler than the bottom layers. The air stream warm up, while traversing the matrix layers.

The lower matrix layers are hotter than the upper ones, therefore, the air stream can effectively transfer heat from the matrix. Improper section of the matrix porosity and the thickness may result in reduced efficiencies since the additional matrix layers beyond on optimum may no longer absorb the solar radiation and heat the air stream further.

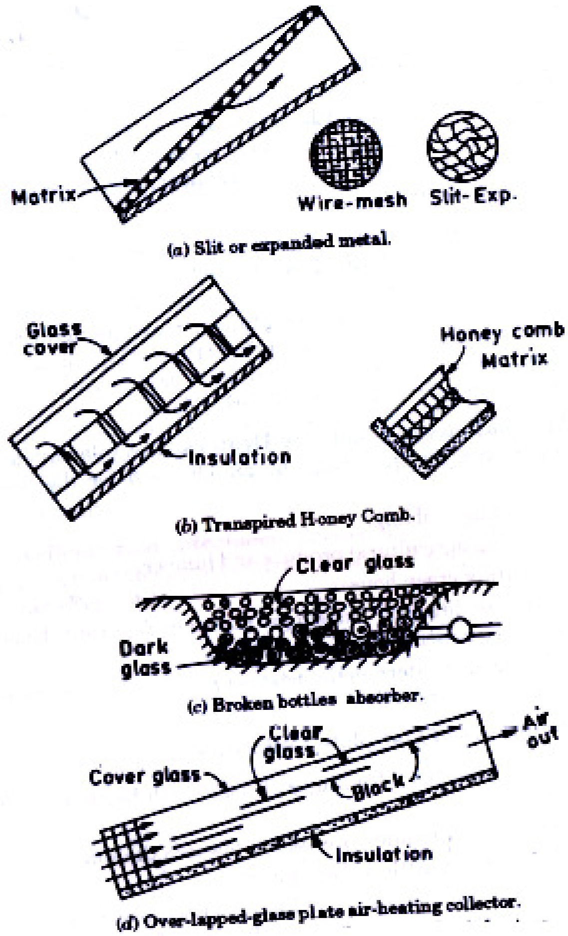


Fig. 2.16. **Sketches of porous absorber-type air heaters.**

(b) The pressure drop for the matrix is usually lower than the non -porous absorber with flow behind the plate since flow per unit cross section would be much lower. Although the matrix hinders the flow, the pressure drops reported for porous matrix absorbers are still lower than for the non-porous absorbers. The solar air heating utilizing a transpired honey comb [Fig. 2.16 *(b)]* is also very favourable from the pressure drop stand point since the flow cross-section is much larger.

Whillier has suggested a method of using crushed glass layers to absorb solar radiation and heat the air. A porous bed, as shown in Fig. 2.16 *(c)* made by forming layers of broken bottles (bottom dark top clear glass), may be readily used for agricultural drying purposes with minimal expenditure.

The overlapped glass plate air heater as shown in Fig. 2.16 *(d)* can be considered as a form of porous matrix, although overall flow direction is along the absorber glass plates instead of being across the matrix. Plate and air stream temperature increase gradually along the collector length and across from top to bottom. Thus thermal losses could be significantly reduced. The pressure drop is also significantly less than the non-porous flat-plate absorber design.

10. Write the Applications of Solar Air Heaters.

The solar air heaters, which supply hot air that could be mainly used for the following processes:

(i) Heating buildings.
(ii) Drying agricultural produce and lumber.
(iii) Heating green houses.
(iv) Air conditioning buildings utilizing desiccant beds or a absorption refrigeration process.
(v) Using air heaters as the heat sources for a heat engine such as a Brayton or Stirling cycle.

11. Briefly discuss about Transmissivity of Cover System in solar system.

Transmissivity like reflectivity and absorptivity, is a function of the wavelength and the angle of incidence of the incoming solar radiation- Other variables which effect the transmissivity are the refractive index *n* and the extinction coefficient *k* of the medium but strictly speaking both n and *k* are also functions of the wavelength λ.

A surface with transmissivity $\tau = 0$ is known as an opaque surface. For such surfaces the sum of the absorptivity *(α)* and reflectivity(ρ) must be equal to unity ($\therefore \tau + \alpha + \rho = 0$). If however, $\tau = 1$, the medium is perfectly transparent. Most real materials are only partially transparent $0 > \tau \leq 1$.

Transmissivity in partially transparent (i.e., translucent) materials is dependent both upon the reflection and absorption of radiation. The problem is usually tackled in two stages:

(i) The transmissivity τ_ρ is first calculated considering reflection alone.

(ii) The transmissivity τ_α then calculated considering absorption alone.

The transmissivity τ, allowing for both reflection and absorption is then given by

$$\tau = \tau_\rho, \tau_\alpha \quad \ldots\ldots\ldots\ldots\ldots.. (1)$$

Since in the most applications there will be a slab of materials involving two faces, reflection at both faces shall have to be considered. Furthermore, the problem is complicated by the fact that the radiation undergoes multiple reflection at both these faces.

Reflection at interfaces. Fresnel has given the relationship for the reflection of non-polarized radiation on passing from one medium to another (Fig. 2.17).

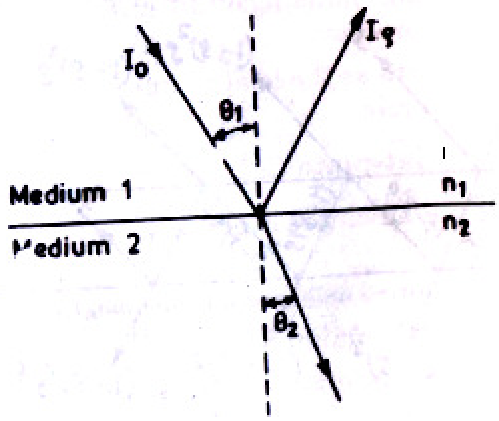


Fig 2.17 Angle of incidence and reflection in two media.

$$\frac{I_\rho}{I_0} = \rho = \frac{1}{2}\left[\frac{\sin^2(\theta_2-\theta_1)}{\sin^2(\theta_2+\theta_1)} + \frac{\tan^2(\theta_2-\theta_1)}{\tan^2(\theta_2+\theta_1)}\right] \quad \ldots\ldots\ldots (2)$$

where $I\rho$ = reflected beam intensity

I_0 = incident beam. radiation

Θ_1 = angle of incidence

Θ_2 = angle of refraction.

In the expression the two terms in the square brackets represent the reflection for each of the two components of polarization. The angles Θ_1 and Θ_2 are related to the indices of refraction.

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3)}$$

Thus if the angle of incidence and refraction indices are known from the above relations one can calculate the reflectance of the single interface.

For radiation at normal incidence,

$$\Theta_1 = \Theta_2 = 0$$

Equations (2) and (3) are combined to give,

$$\rho = \frac{I_\rho}{I_0} = \left[\frac{(n_{1-}n_2)}{(n_{1+}n_2)}\right]^2 \ldots\ldots\ldots(4)$$

Calculation of τ_ρ Cover materials used in solar applications require the transmission of radiation through a slab or film of material and there are thus two interfaces per cover to cause reflection loss. In this situation, the depletion of the beam at the second surface is the same as that at the first, for each component of polarization, assuming cover interfaces are with air on both sides. Neglecting absorption in the slab, as shown in Fig. 2.17 and considering unit incident beam, (1 - ρ) of the incident beam reaches the second interface. Of, this $(1-\rho)^2$ passes through the interfaces and ρ(l- ρ) is reflected back to the first, and so on. Summing up the resulting terms, the transmittance for a single cover neglecting absorption is,

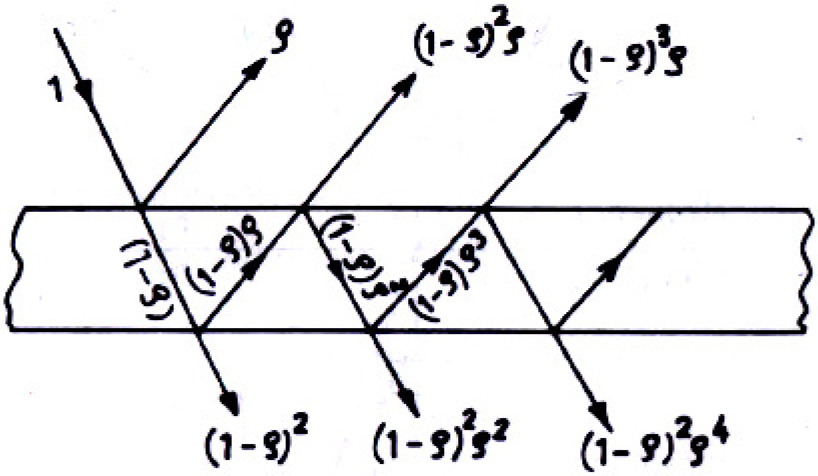


Fig. 2.18. Transmission through one cover.

$$\tau_{\rho-1} = (1-\rho)^2 + (1-\rho)^2\,\rho^2 + (1-\rho)^2\,\rho^4 + \ldots.$$
$$= (1-\rho)^2\,(1 + \rho^2 + \rho^4 + \ldots)$$
$$= (1-\rho^2)\sum_{n=\delta}^{n=\infty} \rho^{2n}$$
$$= (1-\rho)^2 . \frac{1}{1-\rho^2} = \frac{1-\rho}{1+\rho} \qquad \ldots\ldots\ldots\ldots(5)$$

In a similar manner it can be shown that for a system of *n* covers, all are of the same material,

$$\tau_{\rho,\,n} = \frac{1-\rho}{1+(2n-1)\,\rho} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Calculation of τ_α. The absorption of radiation in partially transparent *(i.e.* translucent) materials is described by the Bougers law.

$$dI = kI\,d_x \qquad \ldots\ldots\ldots\ldots\ldots(7)$$

where dI is the diminution in the radiation intensity, *I* is the local value of the intensity, *k* is the constant of proportionality and is called the extinction coefficient. It will be assumed to have a value independent of wavelength, *x* is the distance travelled by the radiation Equation *(7)* can be integrated to give

$$\int_0^L \frac{-dI}{I} = k\int_0^L d_x$$

$$\left[\log I\right]_0^L = \left[-k_x\right]_0^L$$

$$\log I_L - \log I_0 = -k_L$$

or
$$\log \frac{I_L}{I_0} = -k_L$$

or
$$\frac{I_L}{I_0} = e^{-kL}$$

or
$$\tau_\alpha = \frac{I_L}{I_0} = e^{-kL} \qquad \text{............(8)}$$

Note that τ_α is the transmittance considering only absorption and L is the actual path of the radiation through the medium.

For n covers

$$\tau_\alpha = e^{-nkL} \qquad \text{............(9)}$$

when angle of refraction Θ_2 is given, then the path traversed through the cover would be $L/\cos\Theta_2$, Then equation (9) gets modified to form

$$\tau_\alpha = e^{-nkL/\cos\Theta_2} \qquad \text{.........(10)}$$

Now the transmittance allowing for both reflection and absorption can be obtained by the equation (1).

The value of *k* for glass varies from the about 0.01/cm(1 m^{-1}) for absolutely clear 'white glass' to *0.32/cm* (32 m^{-1}) for poor quality glass with a greenish cast of the edges. Note that τ_α is the transmittance considering only absorption and *L* is the actual path of the radiation through the medium.

12. Discuss briefly about Transmittance-Absorptance Product in solar collectors.

Transmittance-Absorptance Product. For solar collector analysis, it is necessary to evaluate the transmittance-absorptance product (τ . *a).* Of the radiation passing through the cover system and striking the plate, some is reflected back to the cover system. However, all this radiation is not lost since some is reflected back to the plate.

The transmissivity-absorptivity product is defined as the ratio of the radiation absorbed in the absorber plate to the radiation incident on the cover system and is denoted by the symbol (τ . *a),* an appropriate subscript *b* or *d* being added to indicate the type of incident radiation *(i.e.* beam or diffuse.) As illustrated in Fig. 2.19, τ is the transmittance of the cover system as can be known from equation (1) and *a* is the angular absorptance of the absorber plate, τ . *a* is absorbed by the absorber plate and (1- *a)* τ, is reflected back to the cover systems. The reflection from the absorber plate is probably more diffuse than specular so that the fraction (1 - *a)* τ that strikes the cover plate is diffuse radiation and (1 - *a)* $\tau\rho_d$ is reflected back to the absorber plate. The quantity ρ_d refers to reflection of the cover plate for incident diffuse radiation that may be partially polarized due to reflections at it is passed through the cover system.

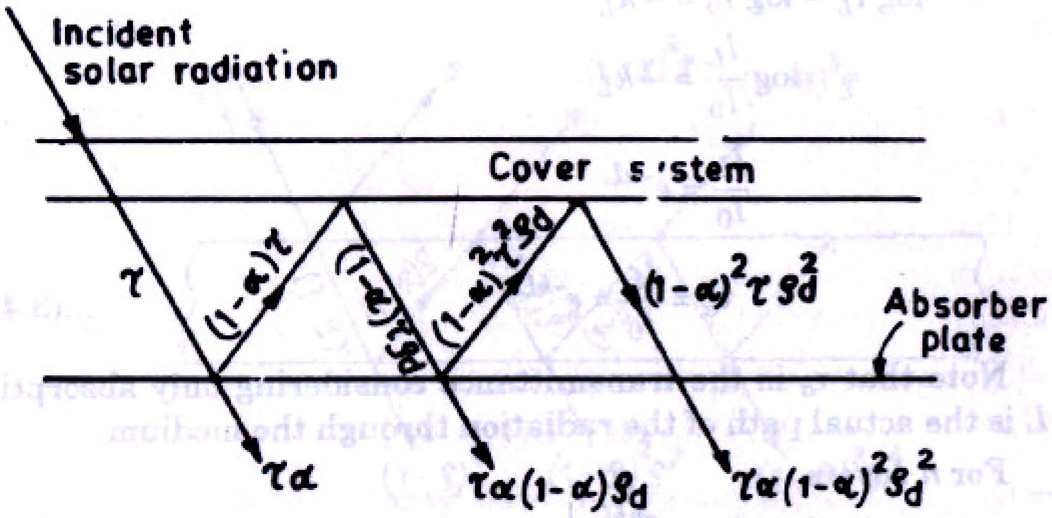


Fig.2.19. Absorption of solar- radiation by absorber plate.

Hence summation yields.

$$
\begin{aligned}
< \tau\alpha > &= \tau\alpha + \tau\alpha\,(1-\alpha)\rho_d + \tau\alpha\,(1-\alpha)^2\,\rho_d^{\,2} \\
&\qquad + \tau\alpha(1-\alpha)^2\,\rho_d^{\,3} + \ldots \\
&= \tau\alpha[1 + (1-\alpha)\rho_d + (1-\alpha)^2\,\rho_d^{\,2} + (1-\alpha)^3\,\rho_d^{\,3} + \ldots] \\
&= \tau\alpha\,\frac{1}{1-(1-\alpha)\,\rho_d} \\
&= \frac{\tau\,.\,\alpha}{1-(1-\alpha)\,\rho_d} \qquad \text{...........(11)}
\end{aligned}
$$

Due to reflection < τα> will be greater τ.α..
For incident angle of 60°, ρ_d is approximately 0.16, 0.24 and 0.29 for one, two and three glasses respectively.

13. Explain briefly about Energy Balance Equation and Collector Efficiency (or) Explain in detail, effect of various parameters on the Performance of a Flat Plate Collector (Nov/Dec 2021)

The performance of solar collector is described by an energy balance that indicates the distribution of incident solar radiation into the useful energy gain and various losses. The thermal losses can be separated into three components:

***(i)* Conductive losses**. An overall heat transfer coefficient value of less than 0.69 W/m^{2}K is suggested to minimize back losses.

***(ii)* Convective losses.** Sizing the air gap between the collector covers at 1.25 to 2.5 cm reduces internal convective losses to the minimum possible level. Convection losses between glass plates can also be inhibited if a honeycomb type, cellular structure is placed between the absorber and the outer window plate. Evacuation of the space between the absorber and the outer cover has been proposed to reduce internal convection and conduction, but the cost of added supports and maintenance of a vacuum are excessive.

***(iii)* Radiative losses**. Radiative losses from the absorber can be reduced by the use of spectrally selective absorber coatings. Such coatings have a high absorptance of about 0.9 in the solar spectrum and a low emittance, usually of the order of 0.1, in the infra-red spectrum in which the absorber radiates to the environment. Selective absorber coating, therefore decrease heat losses and increase collector efficiency.

Under steady conditions, the useful heat delivered by a solar collector is equal to the energy absorbed in the metal surface minus the heat losses from the surface directly and indirectly to the surroundings.

This principle can be stated in the relationship:

$$Q_u = A_c\,[HR\,(\tau.\alpha)_e - U_L\,(t_p - t_a)] \ldots\ldots\ldots\ldots(12)$$

where Q_u is the useful energy delivered by collector, Watts or kcal/hr.

A_c is the collector area, m^2.

HR is the solar energy received on the upper surface of the slopping collector structure; W/m^2 or kcal/hr m^2.

H is the rate of incident beam or diffuse radiation on a unit area of surface of any orientation.

R is the factor to convert beam or diffuse radiation to that on the plane of collector.

Beam and diffuse radiations are considered separately. (τ.α) for radiation is determined from the actual angle of incidence ; (τ.α) for diffuse radiation may be taken as that for beam radiation at an incidence angle of 60°. The symbol *HR* is used to represent the sum of H_bR_b and H_dR_d.

τ is the fraction of incoming solar radiation that reaches the absorbing surface, *transmissivity* (dimensionless).

α is the fraction of solar energy reaching the surface that is absorbed, *absorptivity* (dimensionless).

$(\tau.\alpha)_e$ is effective transmittance absorptance product of cover system for beam and diffuse radiation.

U_L is *the* ***overall heat loss coefficient****.* It is the rate of heat transferred to the surroundings per square metre of exposed collector surface per degree Celsius difference between average collector surface temperature and the surrounding air temperature, $W/m^2\,°C$ (kcal/hr $m^2 °C$).

t_p is the average temperature of the upper surface of the absorber plate.^{0} C.

t_a is atmospheric temperature, °C.

A diagrammatic representation of terms in this relationship shown in Fig. 2.20. In order that the performance of a solar collector be as high as economically practical design and operating factors that increase the value of *HR* (τ.α) in equation (12) and that reduce the value of U_L (t_p - t_a)] are selected. The greater the energy absorption in the metal surface and lower the heat loss from the surface, the higher is the useful recovery. If an unglazed absorber plate is used as the collector, the heat loss coefficient to the atmosphere U_L of 30 to 60W/m^2 °C (35 to 50 kcal/hr. m^2 °C) is so large that an absorber temperature of 15 to 30°C-above atmospheric temperature is the maximum achievable under full solar radiation of 1000 W/m^2 (860 kcal/hr m^2). Under these conditions, on useful heat is delivered from the collector because the heat loss is as large as the solar heat observed. When a fluid is circulated through the collector, useful heat output requires an even lower delivery temperature. Unless a low temperature application is involved, such as swimming pool heating, heat losses must, therefore be reduced.

To reduce the rate of radiation and convection loss as already stated, one or more transparent surfaces, such as glass, are placed above the absorber surface.

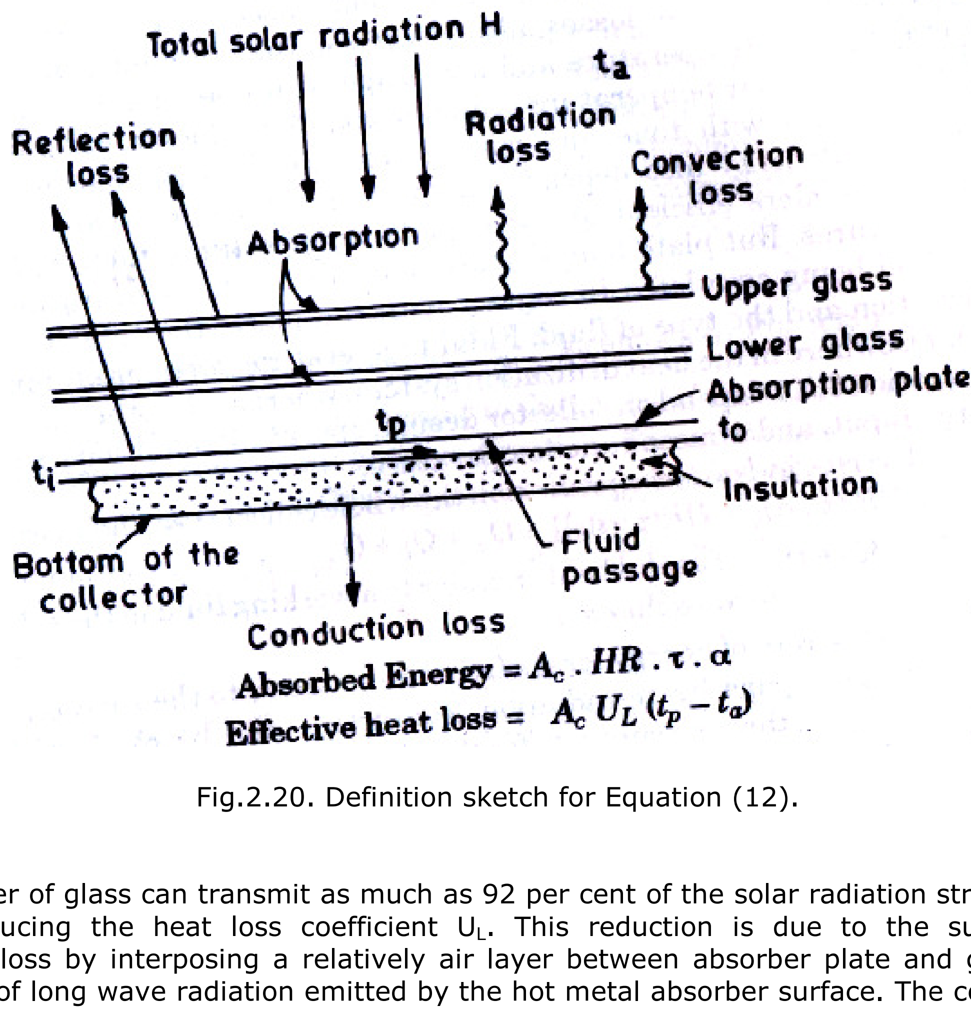


Fig.2.20. Definition sketch for Equation (12).

One layer of glass can transmit as much as 92 per cent of the solar radiation striking it, while greatly reducing the heat loss coefficient U_L. This reduction is due to the suppression of convection loss by interposing a relatively air layer between absorber plate and glass, and by absorption of long wave radiation emitted by the hot metal absorber surface. The combined heat loss coefficient can be reduced to 5 to 10 W/m^2 °C (4.30 to 8.60 kcal/hr m^2 °C) by the use of one glass cover. Similar benefits can be achieved by use of certain transparent plastic materials.

The heat loss coefficient can be reduced further by using a second transparent cover with an air space between the two surfaces. Two convection barriers are then present, as well as two surfaces impeding radiation loss coefficient in the range of 4W/m^2 °C (3.85 kcal/hr m^2°C) are then obtained.

The radiation losses be decreased by other techniques, such as reducing the radiation-emitting characteristics of the absorber. Thermal radiation emitted by the absorber plate may also be reduced reflecting it downward from the lower glass cover by employing an infra-red reflecting coating on the glass. A very thin, optically transparent layer of tin oxide or indium oxide deposited on the glass reflects thermal radiation back to the absorber plate. This coating absorbs some of the solar radiation, however, so the reduced thermal loss is largely offset by reducing solar energy input to the absorber plate.

The foregoing discussion has been concerned with the methods, for reducing *lh,* the heat loss coefficient. By so doing, the total heat loss is minimised and collector efficiency is increased. It is evident from equation (12) that losses also decrease the difference between average plates temperature and air temperature decreases. The ambient (outside) air temperature is an uncontrollable factor, but the fact that it varies with time and with geographic location means that collector efficiency also depends on these factors. It is clear, that a collector is more efficient at lower plate temperatures than at high temperatures. But plate temperature depends on the temperature of the fluid being circulated in contact with the plate, the rate of fluid circulation and the type of fluid. Fluid temperature depends on conditions elsewhere in the heat utilization system, whereas the other factors in equation (12) depend on collector design, operating conditions, solar energy input, and atmospheric temperature.

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

$$A_c \ [\{HR\ (\tau.\alpha)_b + HR(\tau.\alpha)_d\}] = Q_u + Q_l + Q_s \text{ .... } (13)$$

Where Q_u = rate of useful heat transfer to a working fluid in the solar heat exchanger.

Q_l = rate of energy losses from the collector to the surroundings by re-radiation, convection and by conduction through supports for the absorber plate and so on. The losses due to reflection from the covers are included in the (τ.α) terms; and

Q_s = rate of energy storage in the collector.

Collector efficiency llc. is the collector performance and is defined as the ratio of the useful gain over any time period to the incident solar energy over the same time period.

$$\eta_c = \frac{Q_u d_T}{HR d_T} \text{ ....} (14)$$

The bond conductance can be very important in accurately describing collector performance. Simply wiring or clamping of the tubes to the sheet results in a significant loss of performance. It is necessary to have good metal to metal contact so that the bond resistance is less than 0.33 m *°C/W.*

The useful energy gain of the fluid can then be expressed in terms of the known dimensions, the physical parameters and the *local* fluid temperature by solving the equation (9) for T_b and substituting to obtain q_u from Eq. (8).

F^l has been called the *collector efficiency factor.* Physical interpretation of F^1, for most of collector geometries will be clear from equation (12). The denominator is the heat transfer resistance from the fluid to the ambient air, this is equal to $1/U_o$ say. The numerator is the heat transfer resistance from the absorber plate to the ambient air, equal to $1/U_L$, F^l thus is the ratio of these two heat transfer coefficients.

$$F^1 = \frac{U_o}{U_L} \qquad \text{……………(13)}$$

F^l is essentially a constant for any collector design and fluid flow rate. The heat transfer coefficient inside the tube may be assumed, 300W/m^2°C (for natural circulation) or 1500W/m^2°C (forced circulation)

For temperature distribution in the flow direction, consider the energy balance on a fluid element flowing through a pipe of length Δy which is receiving a uniform heat flux q_u refer Fig.2.21 so that

$$\dot{m}C_p T_f \Big| y - \dot{m}C_p T_f \Big|_{y+dy} + \Delta y, q_u = 0 \qquad \text{... (14)}$$

Dividing throughout by Δy and finding the limit as $\Delta y \to 0$, and substituting in Eq. (14) for q_u

$$\dot{m}\, C_p \frac{dT_f}{dy} - WF^1 [S - U_L (T_f - T_a)] = 0 \qquad \text{... (15)}$$

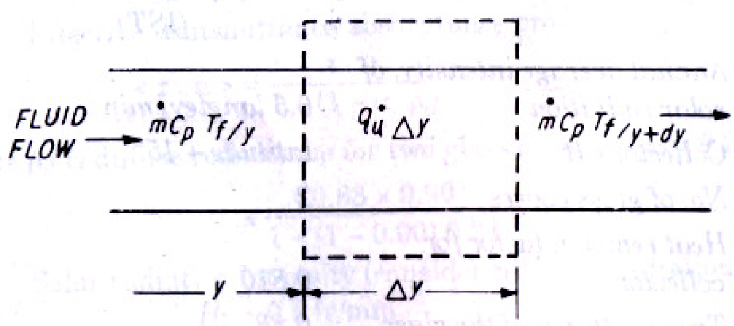


Fig.2.21. Energy balance on fluid element.

If the assumption is made that F^l and U_L are constant (and independent *of y),* then the solution of the differential equation for the temperature at any position (if subject to the condition that inlet fluid temperature is T_{fi}*)* is

14. Data for a flat plate collector used for heating the building are given below:

Factor	*Specification*
Location and latitude	*Baroda, 22°N*
Day and time	*January 1, 11 : 30—12 : 30 (IST)*
Annual average intensity, of solar radiation	*0.5 langley/min*
Collector tilt	*latitude + 15°*
No. of glass covers	*2*
Heat removal factor for collector	*0.810*
Transmittance of the glass	*0.88*
Absorptance of the glass	*0.90*
Top loss coefficient for collector	*7.88 W/m² °C (6.80 kcal/hr m² °C)*
Collector fluid temperature	*60°C*
Ambient temperature	*15°C*

Calculate :

(*i*) *Solar altitude angle,*

(*ii*) *Incident angle,*

(*iii*) *Collector efficiency.*

Solution. Solar declination δ

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

$$= 23.45 \sin\left[\frac{360}{365}(284+1)\right]$$

$$= -23.00°$$

Solar hour angle $\omega_s = 0$, (at mean of 11 : 30 and 12 : 30)

Solar altitude angle α is given by

$$\sin\alpha = \cos\phi\cos\delta\cos\omega_s + \sin\phi_s\sin\delta$$

$$= \cos 22°\cos(-23°)\cos\theta + \sin 22°\sin(-23°)$$

$$= 0.85 - 0.146$$

$$= 0.7036$$

$$\alpha = 44.7°.$$ **Ans.**

Incident angle $\theta = \frac{\pi}{2} - \alpha$

$$= 90 - 44.7° = 45.3°.$$ **Ans.**

Now R_b is given equal to

$$= \frac{\cos(\phi - s)\cos\delta\cos\omega + \sin(\phi - s)\sin\delta}{\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta}$$

$$= \frac{\cos(22° - 37°)\cos(-23°)\cos 0 + \sin(22 - 37)\sin(-23)}{\cos 22\cos(-23)\cos 0 + \sin 22\sin(-23)}$$

$$= \frac{0.889 - 0.101}{0.85 - 0.146} = 1.40$$

Effective transmittance absorptance product is

$$<\tau\,.\,\alpha> = \frac{\tau\,.\,\alpha}{1 - (1 - \alpha)\,\rho_d}$$

where ρ_d is diffuse reflectance for two glass covers, it is = 0.24

$$= \frac{0.88 \times 0.90}{1 - (1 - 0.90)\,0.24} = 0.811.$$

Solar radiation intensity (considering beam radiation only)

$$H_b = 0.5 \text{ ly/mm}$$

$$= \mathbf{0.5\ cal/cm^2.\ min}$$

$$= \frac{0.5 \times 10^4}{10^3} \times \mathbf{60\ kcal/m^2\ hr}$$

$$= 300 \text{ kcal/m}^2 \text{ hr}$$

$$= 350 \text{ W/m}^2 \text{ hr} \qquad [\because\ 1 \text{ kcal} = 1.163 \text{ watt}]$$

Now $S = H_b R_b <\tau\,.\,\alpha>$

$$= 350 \times 1.40 \times 0.811 = 395 \text{ W/m}^2$$

$$(= 340.62 \text{ kcal/hr m}^2)$$

Useful gain $q_u = F_R\,[S - U_L\,(T_{fi} - T_a)]$

$$= 0.810[340.62 - 6.80\,(60 - 15)]$$

$$= 0.810 \times 34.62$$

$$= 28.07 \text{ kcal/hr m}^2. \quad \textbf{Ans.}$$

or $q_u = 0.810\,[395 - 7.88 \times 45]$

$$= 33.21 \text{ W/m}^2 \text{ hr}. \quad \textbf{Ans.}$$

Collection efficiency

$$\eta_c = \frac{q_u}{H_b R_b}$$

$$= \frac{28.07}{300 \times 1.40} = 0.06 = 6\%. \quad \textbf{Ans.}$$

15. Write brief introduction to Concentrating Collector.

Concentrating Collector: Focusing Type

Introduction. Focusing collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface. Such collectors generally use optical system in the form of reflectors or refractors. A focusing collector is a special form of flat-plate collector modified by introducing a reflecting (or refracting) surface (concentrator) between the solar radiations and the absorber. These type of collectors can have radiation increase from low value of 1.5-2 to high values of the order of 10,000. In these collect.ors radiation falling on a relatively large area is focused on to a receiver (or absorber) of considerably smaller area. As a result of the energy concentration, fluids can be heated to temperatures of 500°C or more.

An importance difference between collectors of the non-focusing and focusing types in that the latter concentrate only direct radiation coming from a specific direction, since diffuse radiation arrives from all directions, only a very small proportion is from the direction for which focusing occurs. The optical system directs the solar radiation on-to an absorber of smaller area which is usually surrounded by a transparent cover. Because of the optical system, certain losses (in addition to those which occur while the radiation is transmitted through the cover) are introduced.

These include reflection or absorption losses in the mirrors or lenses and losses due to geometrical imperfections in the optical system. The combined effect of all losses is indicated through the introduction of a term called the *optical efficiency.* The introduction of more optical losses is compensated for by the fact that the flux incident on the absorber surface is concentrated on a smaller area. As a result, the thermal loss terms do not dominate to the same extent as in a flat plate collector and the collection efficiency is usually higher.

16. Explain and Label the different types focusing type concentrating type collectors (or) Discuss about the features of different types of concentrating type solar collectors. Discuss about its applications. (Nov/Dec 2020)

Types of concentrating collectors. Concentrating or focusing collectors may be considered in two general categories: *line focusing* and *point focusing* types. In practice, the line is a collector pipe and the point is a small volume through which the heat transport fluid flows.

Because the sum has a finite size, focusing does infact occur over a small area or volume rather than a line or point. As per the number of Concentrating collector geometries, the main-type of concentrating collectors are:

(a) Parabolic trough collector
(b) Mirror strip reflector
(c) Fresnel lens collector
(d) Flat plate collector with adjustable mirrors
(e) Compound parabolic concentrator (C.P.C.).

Line focusing collectors:

(a)Parabolic Trough Reflector.

The principle of the parabolic trough collector, which is often used in concentration collectors, is shown by the cross-section in Fig.2.22, solar radiation coming from the direction is collected over the area of the reflecting surface and is concentrated at the focus of the parabola, if the reflector is in the form of a trough with parabolic cross-section, the solar radiation is focused alone a line. Mostly cylindrical parabolic concentrators are used, in which absorber is placed along focus axis. The collector pipe, preferably with a selective absorber coating, is used as an absorber.

The dimension of parabolic trough or parabolic cylindrical collector can be vary over a wide range the length of a reflector unit may be roughly 3 to 5 m, and the width about 1.5 to 2.4 m, Ten or more such units are often connected end to end in a row, several rows may also be connected in parallel. Parabolic trough reflectors have been made of highly polished aluminium, of silvered glass or of a thin film of aluminized plastic on a firm base. Instead of having a continuous form, the reflector may be constructed from a number of long flat strips on a parabolic base.

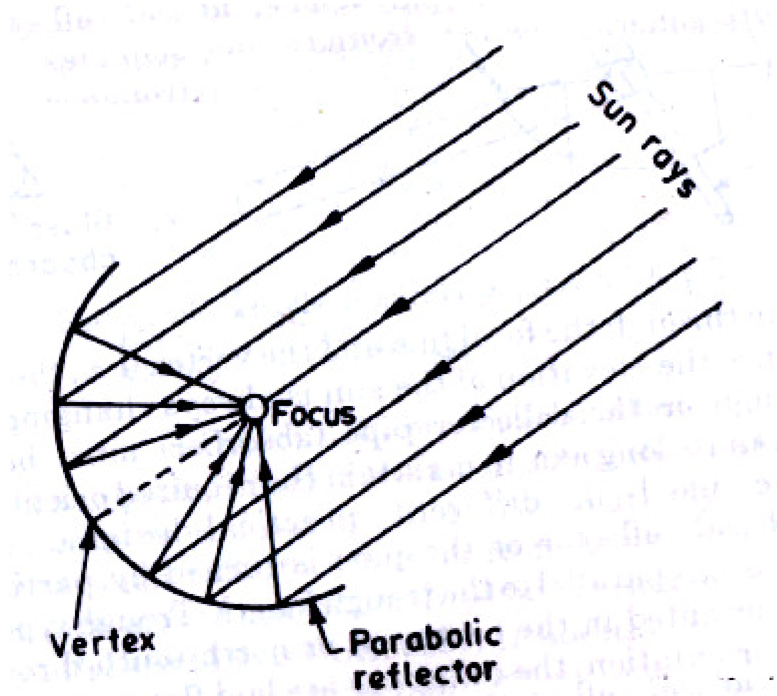


Fig.2.22. Cross-section of parabolic-trough collector

For the solar radiation to be brought to a focus by parabolic trough reflector, the sun must be in such a direction that it lies on the plane passing through the focal line and the vertex (i.e., the base) of the parabola. Since the elevation of the sun is always changing, either the reflector trough or the collector pipe' (absorber) must be turn continuously about its long axis to maintain the required orientation.

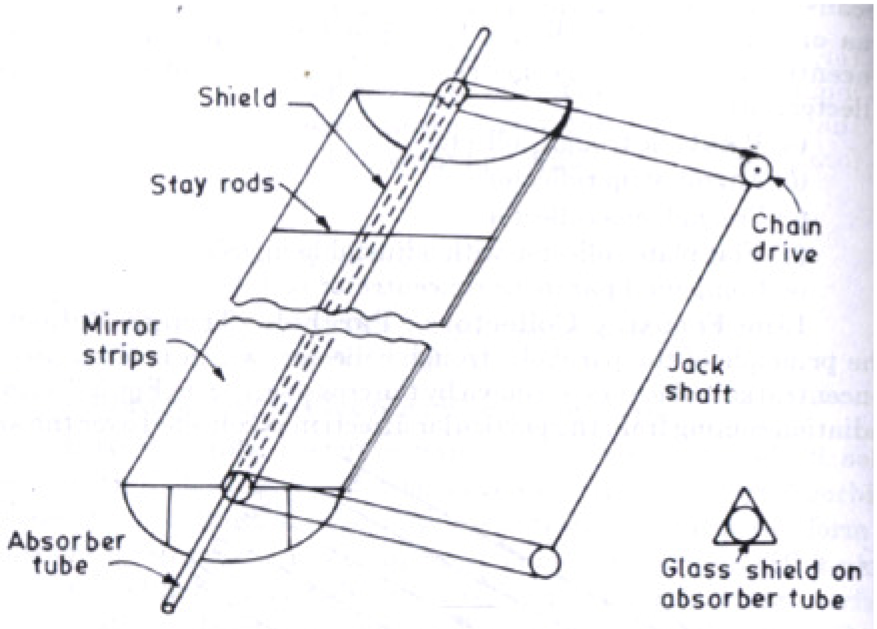


Fig 2.23. A typical cylindrical parabolic system.

Both schemes are used in different practical-designs. Either the trough/cylindrical reflector or the pipe is turned by partial rotation around a single axis parallel to the trough length. Trough type collectors are generally oriented in the east-west or north-south directions. For the east-west orientation, the collectors are laid flat on (or parallel, to) the ground. For the north-south orientation, however, the north end of the trough is raised so that the collectors are sloped facing south-just like flat-plate collectors. Ideally, the slope angle should be changed periodically; it is simpler, but less efficient, however to use a fixed angle design.

The north-south orientation permits more solar energy to be collected t.han the east-west arrangement, except around the winter equinox On the other hand, construction costs are higher for the north-south (sloping) type. Moreover, a system of such collectors requires a larger land area to allow for the shadowing effect of the sloping troughs The increased separation distance between rows of collectors also results in increased pipe line costs and greater pumping and thermal losses.

Finally the sun set position of an east-west reflector is essentially the same as the sunrise position, and little or no evernight adjustment is required. For the north-south orientation, however, the trough (or receiver) must be turned through a large angle from sunset to sunrise. The choice of orientation in any particular instance depends on the forgoing and other considerations.

(b)Mirror-Strip Reflector. In another kind of focusing collector, a number of plane or slightly curved (concave) mirror strips are mounted on a flat base. The angles of the individual mirrors are such that they reflect solar radiation from a specific direction on to the same focal line (Fig. 2.24). The angles of the mirrors must be adjusted to allow for changes in the sun's elevation, while the focal line (for collector pipe) remains in a fixed position. Alternatively, as mentioned for parabolic trough collectors, the mirror strips may be fixed and fixed and the collector pipe moved continuously so as to remain on the focal line.

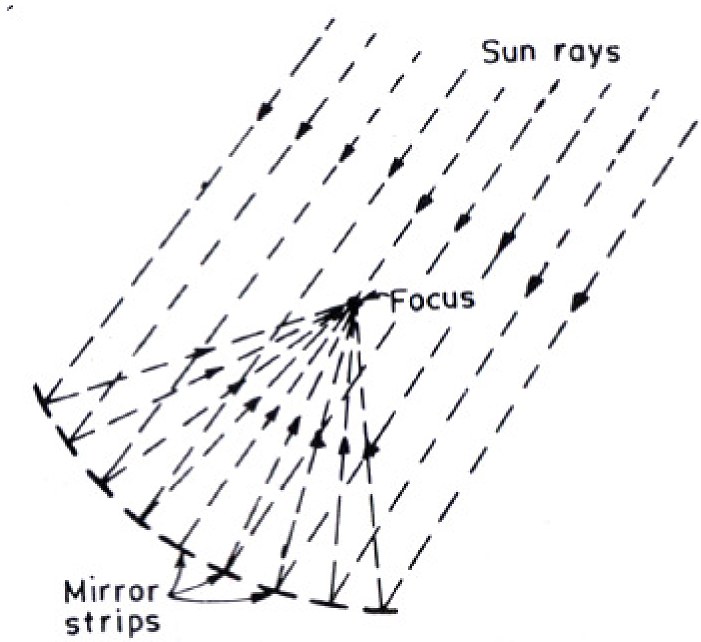


Fig.2.24. Mirror-strip solar collector.

(c) Fresnel Lens Collector. In addition to the reflecting collectors described above, a refraction type of focusing collectors has been developed. It utilizes the focusing effect of a Fresnel lens, as represented in cross-section in Fig. 2.25. For a trough-type collector, the lens is rectangle, about 4.7 m in overall length and 0.95 m in width. It is made in sections from cost acrylic plastic and can probably be produced in quantity at low cost. The rounded triangular trough serves only as a container and plays no role in concentrating the solar energy.

To be fully effective, the Fresnel lens must be continuously aligned with the sun in two directions namely, both along and perpendicular to its length. This is achieved by orienting the troughs in the north-south direction with rotation about the length wise axis ; in addition, the north ends of the troughs are raised to increase the slope as the sun's elevation decreases (and vice versa). The total solar radiation energy that can be collected annually is about 30 per cent greater than for an east-west orientation.

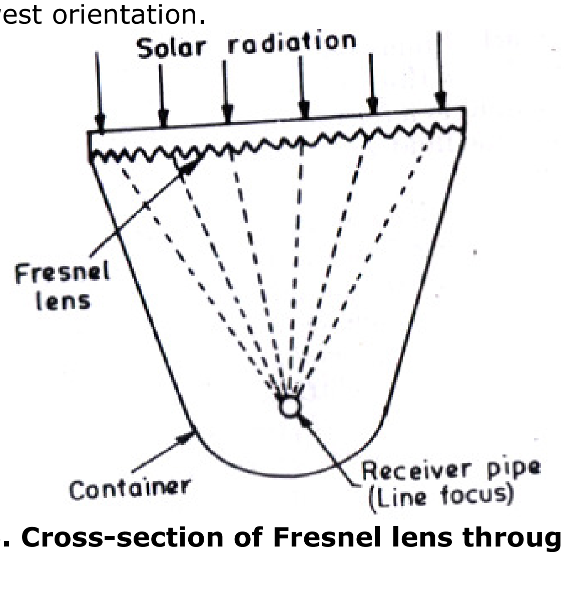


Fig 2.25. Cross-section of Fresnel lens through collector

Receiver pipe. The receiver pipe of a parabolic line focusing collector, shown in cross-section in Fig. 2.26 has the same general characteristics as a flat-plate collector. The solar radiation absorber is a centre steel pipe with a treated surface. A selective absorber surface, such as the black chrome referred to earlier, may be advantageous. A hollow steel plug within the absorber pipe restricts the flow of the heat-transfer fluid to a narrow annular region. This results in a high flow velocity of the fluid and consequently a high rate of heat transfer from the absorber.

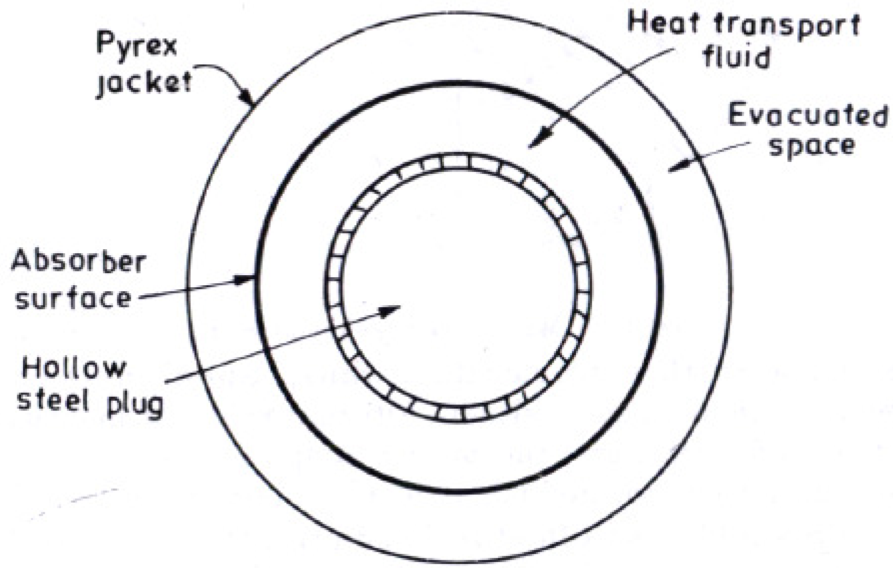


Fig.2.26 Cross-section of solar energy pipe receiver

The absorber pipe is usually enclosed in a glass (Pyrex) jacket in order to decrease thermal losses by convection and radiation. The space between the pipe and the jacket is sometimes evacuated to reduce convection losses. The diameter of the glass jacket may be about 5 cm and that of the absorber pipe about 3 cm. The annulus between this pipe and the plug may be as little as 2.5 mm wide.

In a Fresnel lens collector, the solar radiation is focused into the absorber from the top, rather than from the bottom as in the parabolic (reflection) type. A modified absorber design is then possible Fig. 2.27.

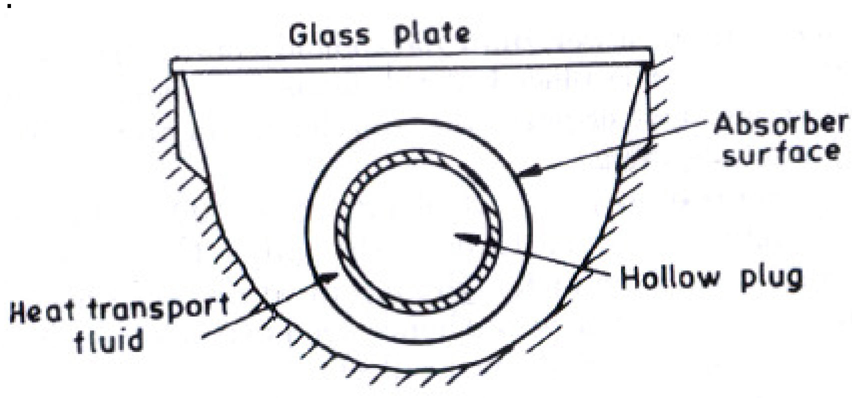


Fig 2.27. Receiver for Fresnel lens collector.

Insulation at the bottom and sides of the absorber pipe and a flat-plate over the top reduce thermal losses. A stainless steel reflector adjacent to the pipe (absorber or receiver) reflects back emitted thermal radiation.

Point Focusing Collector (Paraboloidal Type). A paraboloidal dish collector brings solar radiation to a focus at a point actually a small central volume. (Fig. 2.28). A dish 6.6 m in, diameter has been made from about 200 curved mirror segments forming a paraboloidal surface. The absorber, located at the focus, is a cavity made of a zirconium-copper alloy with a black chrome selective coating. The heat-transport fluid flows into and out of the absorber cavity through pipes bonded to the interior. The dish can be turned automatically about two axes (up-down and left-right) so that the sun is always kept in-a line with the focus and the base (vertex) of the paraboloidal dish. Thus, the sun can be fully tracked at essentially all times.

The concentration ratios (concentration ratio is the ratio of the area of the concentrator aperture to the energy absorbing area of the receiver, it determines the effectiveness of a concentrator) are very high in the case of parabolic system and therefore can be used where high temperatures are required. In a cylindrical parabolic system, the concentration ratio is lower than paraboloid counter-parts. In both the cases, the receiver is placed at the focus i.e., along the focal line in cylindrical parabolic or parabolic trough system and at the focus point in paraboloidal system.

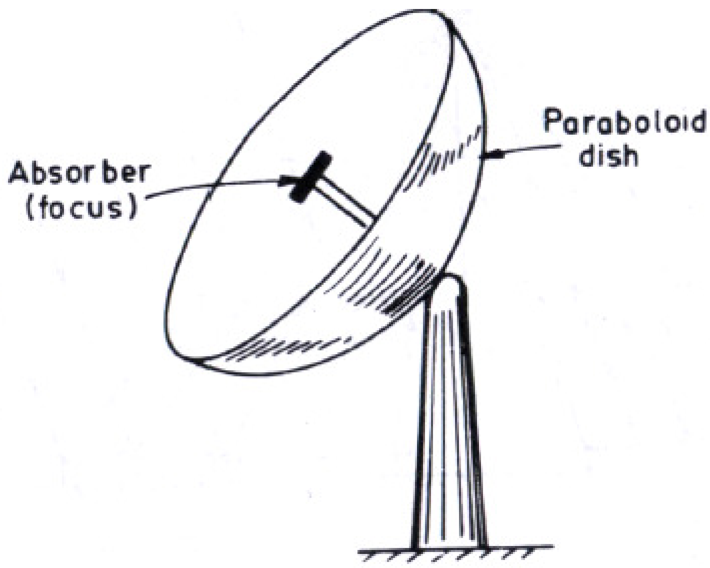


Fig.2.28 Point focus solar collector (Paraboloid).

Concentration ratios of about 30 to 100 or higher would be needed to achieve temperatures in the range 300 to 500°C or higher. Collectors designed for such high concentration ratios necessarily have small angles of field of view and hence need to track the sun continuously. A broad classification of such collector is:

(i) The linear focus collector in the form of a parabolic through or the ones employing faceted mirror strips.

(ii) Spherical and conical mirror (Axicon) with aberrated foci. The physical Upper limit to the concentration ratios achievable with paraboloids and parabolic troughs is determined by their *fld* ratios (focal length/diameter) and are about 10,000 and 100 respectively for the two cases. The concentration ratios achieved in practice are about 1/3 to 1/2 of the above values because of surface irregularities of the reflector, tracking errors etc.

(iii) Central receiver collector, such as the paraboloidal mirror and the tower power plant using heliostat mirrors.

A system equivalent to a very large paraboloidal reflector consists of a considerable number of mirror distributed over an area on the ground. Each mirror, called a ***heliostat,*** can be steered independently about two axes so that the reflected solar radiation is always directed towards an absorber mounted on a tower (Fig. 2.29). This type of collector is classified as ***Central Receiver Collector.*** This is mostly used in tower power plants for generation of electrical energy.

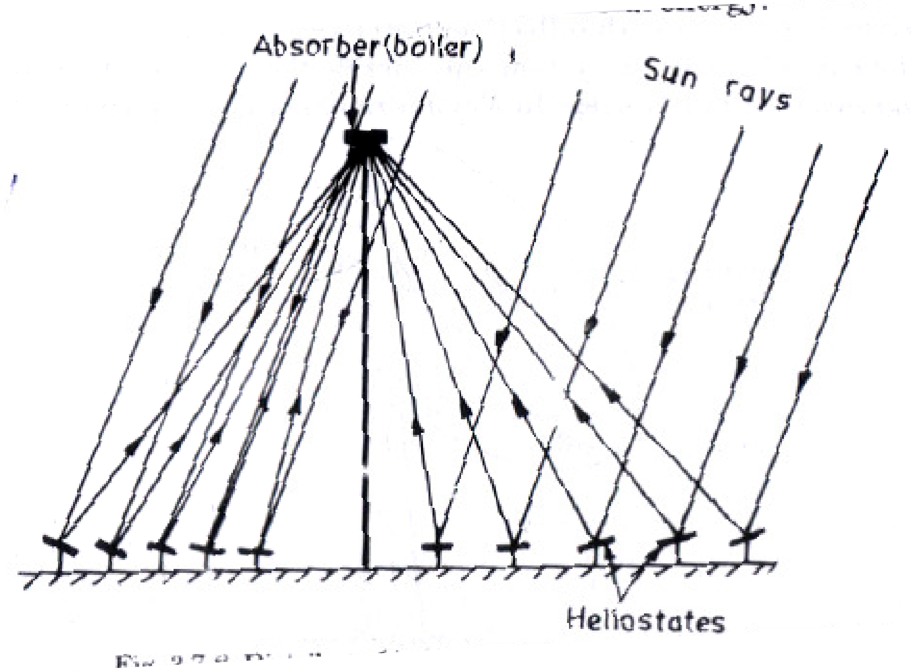


Fig 2.29. Distributed heliostat point-focusing reflector (Central-Receiver).

In the typical central receiver, the mirror is composed of many small mirrors; each with its own heliostat to follow the sun. The heliostats are generally located in the horizontal plane, but when the situation is favorable, can simply follow the existing terrain. The basic difference between a single mirror concentrator and the heliostat system is that the heliostat system has a *dilute mirror.* This means that the entire surface within the system is not covered with mirror surface. This diluteness is generally termed as the *fill factor.* A central receiver with a fill factor of 40% means that 40% of the land area is covered by the mirrors.

In a central receiver optical system as shown in figure many small mirrors are separately mounted to act together like a dilute paraboloid. The basic problem associated with the central receiver is that the heliostat mirrors require non-linear drive rate in two co-ordinates to achieve the requirement of keeping the reflected image point on a fixed receiver. Along with the problem is the requirement that the heliostat be rugged enough to survive storms and operate successfully in a moderate wind.

Among all the steerable concentrators mentioned above paraboloids have the highest efficiency in terms of the utilization of the reflector area because in a fully steerable paraboloid there are no losses due to aperature effects. Also radiation losses are small because of the small area of the absorber at the focus. Both then they are the most difficult to fabricate and operate too. A practical size for aperature area would be about 50 m^2 from which 15 to 20 kW of useful energy could be extracted by thermal conversion processes.

Concentrating Collectors: Non-Focusing Type. The simplest type of concentrating collector is the mirror-boosted, flat plate collector. It consists of a flat plate facing south with mirrors attached to its north and south edges (Fig. 2.30). If the mirrors are set at the proper angle, they reflect solar radiation on to the absorber plate. Thus, the latter receives reflected radiation in addition to that normally falling on it. The mirrors cut off part of the scattered radiation that would otherwise have reached the absorber plate, and only part of the scattered radiation falling on the mirrors will be reflected onto the absorber. Thus the concentration effect arises mainly from the increase in direct radiation reaching the absorber plate.

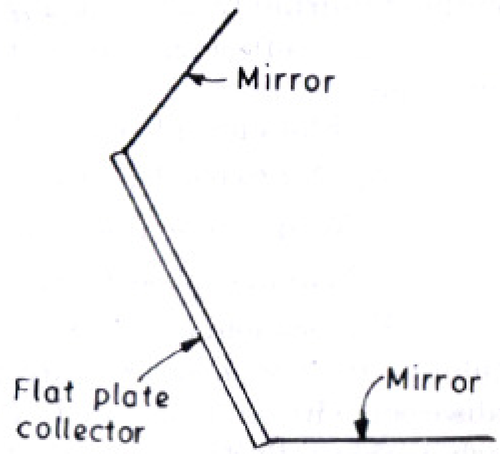


Fig 2.30. Flat-plate collector augmented with mirrors.

When a number of collectors are combined in two or more rows, as they often are, the rows must be set further apart in the north-south directions to allow for the additional sun shading caused by the mirror extensions. Furthermore, in order for the mirrors to be effective, the angles should be adjusted continuously as the sun's attitude changes. For these reasons, and they can provide only a relatively small increase in the solar radiation falling on the absorber, flat-plate collectors with mirrors are not widely used.

Compound Parabolic Concentrator (CPC). The CPC (or Winston Collector) is a trough-like arrangement of two facing parabolic mirrors (Fig. 2.31). Unlike the single parabolic trough reflector described earlier, the CPC is nonfocusing, but solar radiation from many directions is reflected toward the bottom of the trough. Because of this characteristic; a large proportion of the solar radiation, including diffuse (scattered) radiation, entering the trough opening is collected (and concentrated) on a small area. In addition to collecting both direct and diffuse radiations, an advantage of the CPC is that it provides moderately good concentration, although less than a focussing collector, in an east-west direction without (or only seasonal) adjustment for sun tracking.

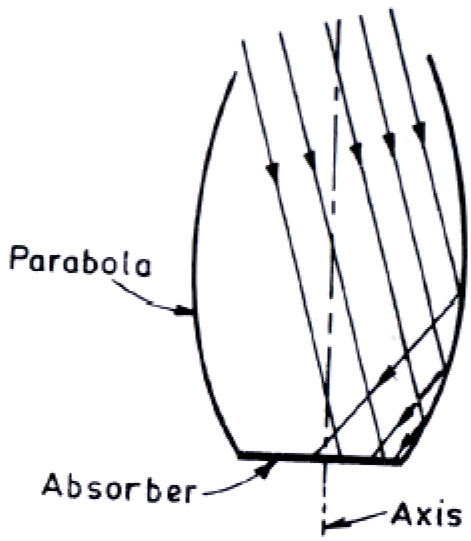


Fig.2.31.Compound parabolic concentrator

It is possible to concentrate solar radiation by a factor of 10 without diurnal tracking, using this type of collector. CPC reflectors can be designed for any absorber shapes: For example

(a) Flat one sided absorber,
(b) Flat two sided absorbers (fin),
(c) Wedge-like absorbers, or
(d) Tubular absorbers.

For economic as well as for thermal reasons the fin and the tubular type of absorbers are preferable. With a concentric tubular absorber with an evacuated jacket, temperatures of about 200°C are achievable with Winston collectors. They are suitable for the temperature range of 100-150 ^{0}C even if the absorber is not surrounded by a vacuum. It is claimed that Winston collectors are capable of competitive performance at high temperatures of about 300 ^{0}C required for power generation, if they are used with selectively coated, vacuum enclosed receivers which decrease thermal losses from the collector.

The **advantages** of this new type are:

(i) There is no need for tracking, as it has high acceptance angle, only seasonal adjustments are required. For concentration ratios of ~3, even seasonal adjustments may not be required.

(ii) The efficiency for accepting diffuse radiation is much larger than conventional concentrators, and,

(iii) Its concentration ratio is equal to the maximum value possible for a given acceptance angle.

The parabolic trough or a linear parabolic collector is also more commonly known as the cylindrical parabolic collector. It has many commercial versions which are now available.

Out of all configurations described so far, the maximum concentration ratios are available with paraboloidal system, it is of the order of 10,000.

17. Examine the Advantages and Disadvantages of Concentrating Collectors over Flat-Plate Type Collectors.

Advantages and Disadvantages of Concentrating Collectors over Flat-Plate Type Collectors.

Advantages.

The main advantages of concentrator systems over flat-plate type collectors are:

1. Reflecting surfaces required less material and are structurally simpler than flat-plate collectors. For a concentrator system the cost per unit area of solar collecting surface is therefore potentially less than that for flat-plate collectors.

2. The absorber area of a concentrator system is smaller than that of a flat-plate system for same solar energy collection and therefore the insolation intensity is greater.

3. Because of the area from which heat is lost to the surroundings per unit of the solar energy collecting area is less than that for flat-plate collector and because the insulation on the absorber is more concentrated, the working fluid can attain higher temperatures in a concentrating system than in a flat-plate collector of the same solar energy collecting surface.

4. Owing to the small area of absorber per unit of solar energy collecting area, selective surface treatment and/or vacuum insulation to reduce heat losses and improve collector efficiency are economically feasible.

5. Focusing or concentrating systems can be used for electric power generation when not used for heating or cooling. The total useful operating time per year can therefore be large for a concentrator system than for a flat-plate collector and the initial installation cost of the system can be regained by saving in energy in a shorter period of time.

6. Because the temperature attainable with concentrating collector system is higher, the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator systems than for flat-plate collectors.

7. In solar heating and cooling applications, the higher temperature of the working fluid attainable with a concentrating system makes it possible to attain higher efficiencies, in the cooling cycle and lower cost for air conditioning with concentrator systems than with flat-plate collectors.

8. Little or no anti-freeze is required to protect the absorber in a concentrator system whereas the entire solar energy collection surface requires anti-freeze protection in a flat-plate collector.

Disadvantages

1. Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse component cannot be reflected and is thus lost.

2. In some stationary reflecting systems it is necessary to have a small absorber to track the sun image ; in others the reflector may have to be adjustable more than one position if year round operation is desired; in other words costly orienting systems have to be used to track the sun.

3. Additional requirements of maintenance particular to retain the quality of reflecting surface against dirt, weather, oxidation etc.

4. Non-uniform flux on the absorber whereas flux in flat-plate collectors is uniform.

5. Additional optical losses such as reflectance loss and the intercept loss, so they introduce additional factors in energy balances.

6. High initial cost.

18. With the help of neat sketch explain the construction and working of central receiver collector. Where they are used? What are its advantages? (Nov/Dec 2021)

Central receiver collector:

Central receiver collector, such as the paraboloidal mirror and the tower power plant using heliostat mirrors.

A system equivalent to a very large paraboloidal reflector consists of a considerable number of mirror distributed over an area on the ground. Each mirror, called a ***heliostat,*** can be steered independently about two axes so that the reflected solar radiation is always directed towards an absorber mounted on a tower (Fig. 2.32). This type of collector is classified as ***Central Receiver Collector.*** This is mostly used in tower power plants for generation of electrical energy.

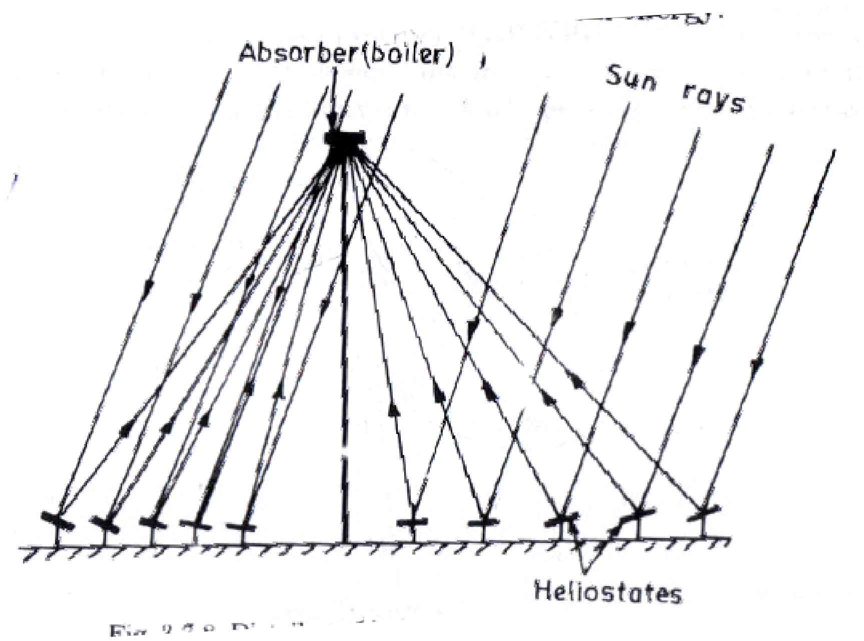


Fig 2.32. Distributed heliostat point-focusing reflector (Central-Receiver).

In the typical central receiver, the mirror is composed of many small mirrors; each with its own heliostat to follow the sun. The heliostats are generally located in the horizontal plane, but when the situation is favorable, can simply follow the existing terrain. The basic difference between a single mirror concentrator and the heliostat system is that the heliostat system has a *dilute mirror.* This means that the entire surface within the system is not covered with mirror surface. This diluteness is generally termed as the *fill factor.* A central receiver with a fill factor of 40% means that 40% of the land area is covered by the mirrors.

In a central receiver optical system as shown in figure many small mirrors are separately mounted to act together like a dilute paraboloid. The basic problem associated with the central receiver is that the heliostat mirrors require non-linear drive rate in two co-ordinates to achieve the requirement of keeping the reflected image point on a fixed receiver. Along with the problem is the requirement that the heliostat be rugged enough to survive storms and operate successfully in a moderate wind.

Among all the steerable concentrators mentioned above paraboloids have the highest efficiency in terms of the utilization of the reflector area because in a fully steerable paraboloid there are no losses due to aperature effects. Also radiation losses are small because of the small area of the absorber at the focus. Both then they are the most difficult to fabricate and operate too. A practical size for aperature area would be about 50 m^2 from which 15 to 20 kW of useful energy could be extracted by thermal conversion processes.

Advantages:

Central receiver systems are considered to have a large potential for mid-term cost reduction of electricity compared to parabolic trough technology, because they can achieve higher temperatures, resulting in more efficient steam cycles or ultimately higher energy cycles using gas turbines at temperatures above 1000°C to further increase efficiency and throughput.

19. Calculate the useful gain, exit fluid temperature and collection efficiency for a cylindrical parabolic concentrator system of 2m width and 8m length. The absorbing cylinder has a diameter of 6 cm and the transparent cover has a diameter of 9 cm optical properties are estimated as

$\rho = 0.85$, $(\tau.\alpha) = 0.77$, $\gamma = 0.94$

Heat transfer coefficient from fluid inside to surroundings,

U_o = 5.2 kcal/hr m^2 °C (6.04 W/m2 ^{0}C),

Heat transfer coefficient from absorber cover surface to surrounding

U_L = 6.0 hcal/hr-m^2 °C (6.98 W/m^2 ^{0}C).

The incident beam radiation on the aperture of the collector is 600 kcal/ hr m^2 (698 W/m^2) and the ambient temperature is 25°C. The collector is designed to heat a fluid entering the absorber at 150°C, at a flow rate of 400 kg/hr. The fluid has

C_p= 0.30 kcal/kg °C (1.256 kJ/kg ^{0}C).

Solution. A_r = area of the receiver pipe

$= \pi D_0 L$

$= \pi \times 0.06 \times 8 = 1.51 \text{ m}^2$

A_a = aperture area of the concentrator

$= (W - d_{co}) \times L$

where W = width of concentrator

d_{co} = diameter of transparent cover

L = length of concentrator

$A_a = (2 - 0.09) \times 8 = 15.28 \text{ m}^2$

= collector efficiency factor,

$$F' = \frac{U_o}{U_L} = \frac{5.2}{6} = 0.86$$

Heat removed factor F_R is

$$= \frac{\dot{m}\, C_p}{A_r\, U_L}\left[1 - e^{-\frac{A_r\, U_L\, F'}{\dot{m}\, C_p}}\right]$$

$$\frac{\dot{m}\, C_p}{A_r\, U_L\, F'} = \frac{400 \times 0.30}{1.51 \times 6 \times 0.86}$$

$$= 15.4012$$

$$F_R = 15.4012 \times 0.86 \times \left(1 - e^{-\frac{-1}{15.4012}}\right)$$

$$= 0.8329.$$

The absorbed solar energy is

$$S = H_b R_b\, \rho\gamma\, (\tau.\alpha)$$

$= 600 \times 0.85 \times 0.94 \times 0.77$

$= 370 \text{ kcal/hr m}^2$ ...... (MKS)

$= 430 \text{ W/m}^2$ ...... (SI).

The values of F', F_R will be same in any unit, since they are factors (dimensionless).

Useful gain,

$$\text{(In M.K.S. unit) } Q_u = A_a \times F_R \left[S - \frac{A_r U_L}{A_a}(T_{fi} - T_a) \right]$$

$$= 15.28 \times 0.8326 \left[370 - \frac{1.51 \times 6}{15.28}(150 - 25) \right]$$

$$= 3750 \text{ kcal/hr. } \textbf{Ans.}$$

$$\text{(In S.I. unit) } Q_u = 15.28 \times 0.8326 \left[430 - \frac{1.51 \times 6.98}{15.28}(150 - 25) \right]$$

$$= 4360 \text{ watt. } \textbf{Ans.}$$

The exit fluid temperature can be obtained from

$$Q_u = \dot{m} C_p (t_{co} - t_{ci})$$

where t_{co} = collector fluid temperature at outlet.

t_{ci} = Fluid inlet temperature

$$t_{co} = t_{ci} + \frac{Q_u}{\dot{m}\, C_p}$$

$$= 150 + \frac{3750}{400 \times 0.30} \text{ or } \left[150 + \frac{4360}{400 \times \frac{1.256}{3.6}} \right]$$

$$= 181°\text{C. } \textbf{Ans.}$$

$$\eta_{collection} = \frac{Q_u}{A_a H_b R_b}$$

$$= \frac{3750}{16 \times 600} \times 100 \quad \text{or} \quad \left(\frac{4360}{16 \times 698} \times 100 \right)$$

$$= 39\%. \textbf{ Ans.}$$

Solar thermal applications

20. Describe the process principles, process and functions of Solar Pond.

Introduction.

A natural or artificial body of water for collecting and absorbing solar radiation energy and storing it as heat Thus a solar pond combines solar energy collection and sensible heat storage.

The simplest type of solar pond is very shallow, about 5 to 10 cm deep, with a radiation absorbing (e.g., black plastic) bottom. A bed of insulating material under the pond minimizes loss of heat to the ground. A curved cover, made of transparent fibre glass, over the pond permits entry of solar radiation but reduces losses by radiation and convection (i.e., air movement). In a suitable climate, all the pond water become hot enough for use in space heating and agricultural and other processes In shallow solar pond, as described above, the water soon Acquires a fairly uniform temperature. However, experience shows that the water in such a pond usually heats up only a few degrees, because of the natural convection currents which are set into motion as soon as heat is absorbed at the bottom. In a deeper pond also temperature variations generally exist. Loss of heat from the surface, especially at night, then results in circulation of water by convection. The situation is changed if the pond contains salt water at the bottom with a layer of fresh water above it. Because of its salt content, the solar pond bottom water is more dense than the cooler fresh water at the top, and hence it does not tend to rise. A relatively stable layer of heated salt water is thus produced at the bottom of the pond with a lighter layer of cooler fresh water, which acts as a heat insulator, above it. Thus a 'solar pond' defined as an artificially constructed pond in which significant temperature rises are caused to occur in the lower regions by preventing convection. The more specific terms 'salt-gradient solar pond' or 'nonvecting solar pond' are also often used, as to distinguish these ponds from' shallow solar pond'.

Solar ponds promise an economical way over flat-plate collectors and energy storage by employing a mass of water for both collection and storage of solar energy. The energy is stored in low grade (60 to 100°C) thermal form which, in self, might be suitable for a variety of applications such as space heating, industrial process heat and to obtain mechanical and/or electrical energy.

Ponds have been studied experimentally and analytically at the national Physical Laboratory of Israel and by others. 'I'abour (1964) outlines the general concept and the major problems. Tabour and Merz 1965) carried out theoretical investigations of underlying physics of the Solar pond and laboratory and field tests, to study the many factors affecting pond performance. At MIT, Stolzenbach (1968) developed numerical methods to predict temperature distributions within the solar pond. A group of Russian scientists at the Uzbek SSR Academy of Science (1973) has been actively engaged in very detailed and sophisticated research of the relevant physics. In India Dr. G.C. Jain 1973)has designed and is operating a solar pond for use in production Of salt at the Central Salt and Marine Chemical Research Institute in Bhavnagar. Work has also been done at Pondicherry, where experimental studies have been conducted on a pond 100 m2 in area and 2 m deep.

Principle of operation and description of non-convective solar pond.

A solar pond is a mass of shallow water about 1 or 2 meters deep with a large collection area, which acts as a heat trap. It contains dissolved salts to generate a stable density gradient. Part of the incident solar radiation entering the pond surface is absorbed throughout the depth and the remainder which penetrates the pond is absorbed at the black bottom. If the pond were initially filled with fresh water, the lower layers would heat up, expand and rise to .the surface.

Because of the convective mixing and heat loss at the surface only a small temperature rise in the pond could be realized. On the other hand, convection can 'be eliminated by initially creating a sufficiently strong salt concentration gradient. In this case, thermal expansion in the hotter lower layers is insufficient to destabilize the pond. With convection suppressed, the heat is lost from the lower layers only by conduction. Because of the relatively low conductivity, the water acts as an insulator and permits high temperature (over 90°C) to develop in the bottom layers. At the bottom of the pond, a thick durable plastic liner is laid. Materials used for the liner include butyl rubber, black polyethylene and hypalon reinforced with nylon mesh. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water, the concentration varying from 20 to 30 percent at the bottom to almost zero at the top.

In the salt-gradient solar ponds, dissolved salt is used to create layer of water with different densities-the more salt, the denser water The concentration of the salt at the surface is low-usually less than 5 percent by weight and thus the water is relatively light. The salt concentration steadily increases with depth until at the bottom where it is very high, around 20 per cent. Thus a solar pond has three zones following (fig 2.33) salinity with depth:

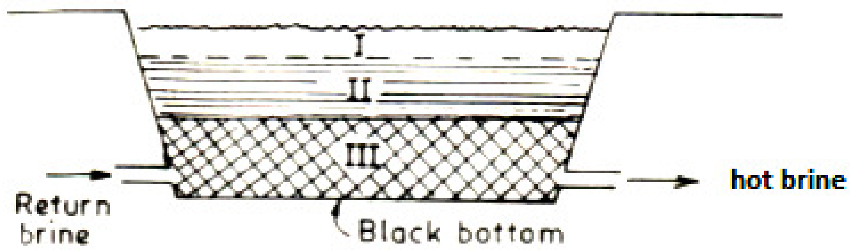
{i) Surface convective zone or upper convective zone

(0.3-0.5 m), salinity < 5%.

(ii) Non-convective zone 1to 1.5 m, salinity increases with depth.

(iii) Storage zone or lower convective zone

1.5 to 2 m, salinity = 20%



(i) Surface convective zone.
(ii) Non-convective zone.
(iii) Storage zone.

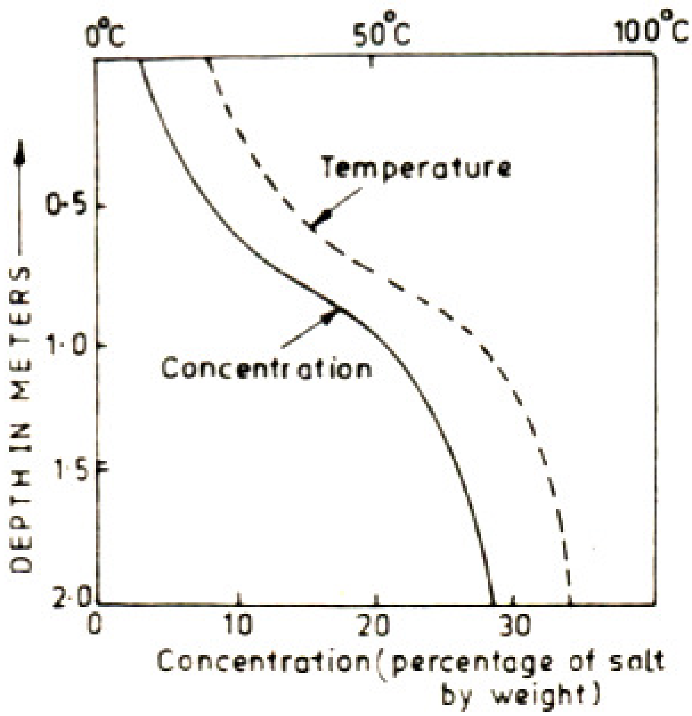


Fig 2.33 temperature and concentration profile for a typical pond

In the above classification of zone, a solar pond of 2 metres depth Is considered for, illustration, whereas depth may vary from 1 to 2 metres. At the bottom is the storage zone, which is typically one or two metres deep but can be as little as half a metre, or as much as several metres deep. The surface convective zone usually has a small thickness, around 10 to 20 cm. It has a low, uniform concentration which is close to zero, as well as a fairly uniform temperature, which is close to the ambient air temperature. The non-convective zone is much thicker and occupies more than half the depth of the pond. Both concentration and temperature increase with depth in it. It serves mainly as an insulating layer and reduces heat loss in the upward direction. This part acts as a thermal storage as some of the heat collection also takes place in this zone. The lower convective zone or storage zone is comparable in thickness to the non-convective zone. Both the concentration and temperature are nearly constant in this zone. It serves as the main heat collection as well as thermal storage medium. The deeper the zone, the more heat is stored. The lowest zone traps heats for the long periods, damping the effects of daily and even seasonal change. This capacity for low cost storage is one of the chief advantages of salt-gradient solar ponds; they can be tapped for energy at night as well as during the day. even during long periods of cloud cover or even ice cover the stored energy is still available. As salty water near the bottom heats up, it expands. However it cannot rise because it is denser than the less salty water above. Thus the solar pond is 'non-convecting'. the warmed water trapped below.

Some heat is still lost by conduction to the surface, but this process is much weaker than convection. Lower waters may even warm upto and above the boiling point of pure water. The highest temperature ever recorded in a solar pond is 108°C, set in the summer of 1980 at the University of New Maxico, in Albuquerque.

Depending on location, water clarity and temperature, the solar Can capture 10 to 20 per cent of the solar energy hitting its surface. Hence, each square metre of pond surface area can supply one half to giga joules of thermal energy per year at temperatures from 40°C 80^{0}C. A flat plate collector of the same area would be twice as efficient but cost ten times as much.

The salt used in a solar pond for creating density gradient should have the following characteristics:

1.It must have a high value of solubility to allow high solution densities

2. The solubility should not vary appreciably with temperature

3. Its solution must be adequately transparent to solar radiation

4. It must be environmentally benign, safe to handle the ground water.

5. It must be available in abundance near site so that its total delivered cost is low, and

6. It must be inexpensive.

Stability of non-convective layer in the presence of a temperature gradient can be maintained by creating, a sufficiently steep salt concentration gradient. In order to generate the initial salt concentration gradient required to prevent convection, the usual practice is to fill the pond with several layers of salt solution with the successive layers changing stepwise in concentration from near saturation at the bottom to fresh water at the top. For a typical pond of 1metre deep, one might use six or eight layers. Less layers can be floated successively on the top of the existing ones, or successively, more dense layers can be put in at the pond bottom flowing in as under currents and gradually lifting the whole pond. Because of the turbulent mixing and molecular diffusion which occur during filling, the staircase type concentration profile evolves into a smooth nearly uniform concentration gradient. Typical value of salt concentration at the top surface is 20 kg/cubic metre increasing to 300 and 260 kg/cubic metre, for magnesium chloride and sodium chloride respectively, at the bottom. It is necessary to add periodically concentrated solutions at the bottom, and wash the surface with fresh water to maintain the concentration gradient in the presence of diffusion effects.

Extraction of Thermal Energy.

Energy is stored in low grade thermal form of the lower convective zone. Convection in the ozone is due to the process of heat extraction, accomplished by hot brine withdrawal and cool brine return. It is not practical to cover the bottom of the pond with an array of pipes acting as a heat exchanger due to two reasons.

(i) the cost will increase sharply in the case of large ponds of the size of about a square km ; and *(ii)* unless there is convection around the pipes heat transfer from the stationary hot brine to the fluid in the pipes will be very poor.

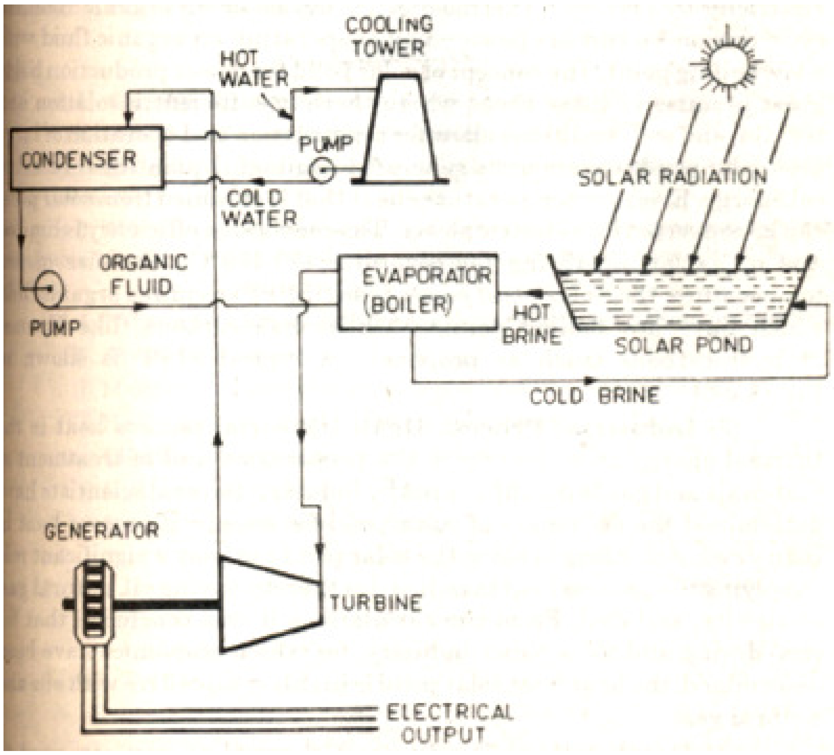


Fig 2.34 Solar pond electric power plant with cooling tower

Extraction of thermal energy stored in the lower layers of the pond can be easily accomplished without disturbing the non-convecting salt gradient zone above. Hot water can be extracted from a solar pond without disturbing the concentration gradient. This is achieved by installing the water outlet at the same height as the water inlet. Hot brine can be withdrawn and cool brine returned in a laminar flow pattern because of the presence of density gradient. For small or model ponds, heat exchangers consisting of pipes can be placed in the hot lower layers, but this entails not only the initial installation cost but the continued pumping losses associated with the heat transfer fluid.

Thermal energy from solar pond is used to drive a Rankine cycle heat engine. Hot water from the bottom level of the pond is pumped to the evaporator. Where the organic working fluid to vaporized (Refer fig 2.34.). The vapour flows under high pressure to the turbine and Thereby expanding through the turbine wheel and the electric generator Linked to it. The vapour then travels to the condenser where cold water from the cooling tower condenses the vapour back it to a liquid. The liquid is pumped back to the evaporator where the cycle is repeated.

A 2000 sq. m solar point equipped with a 20 kW engine has been constructed in Australia.

21. Explain the various Applications of Solar Ponds in details.

Some of the applications of a solar pond are discussed below:

(1) Heating and Cooling of Buildings. Because of the large heat storage capability in the lower convective zone of the solar pond, it has ideal use for heating even at high latitude stations and for several cloudy days. Many scientists have attempted and sized the solar pond for a particular required heating load for house heating. Calculating have shown that a solar pond with a 100m diameter and 1 m deep lower convective zone is sufficient to drive either an absorption system or chillier capable of meeting 100 'percent of typical cooling load of a 50 house community in Fortworth (U.S.A).

(2) Production of Power. A solar pond can be used to generate electricity by driving a thermo-electric device or an organic rankine cycle engine-a turbine powered by evaporating an organic fluid with a low boiling point. The concept of solar pond for power production holds great promise in those areas where there is sufficient insolation and terrain, and soil conditions allow for construction and operation of large area solar ponds necessary to generate meaningful quantities of electrical energy. Even low temperatures heat that is obtained from solar pond can be converted into electric power. The conversion efficiency is limited due to its low operating temperatures (70-100·C). Because of low temperature, the *Solar pond power plant* (SPPP) requires organic fluid which have low boiling points such as halo-carbons (like freons) or hydrocarbons (such as propane). A typical SPPP is shown in fig

(3) Industrial Process Heat. Industrial process heat is the thermal energy used directly in the preparation and of treatment of materials and goods manufactured by industry. Several scientists have determined the economics of solar pond for supply of process heat in industries. According to them the solar pond can play a significance role supplying the process heat to industries thereby saving oil, natural gas electricity, and coal. From the calculations it was concluded that for crop drying and for a paper industry, for which economics have been determined, the heat from solar pond is highly competitive with oils natural gas.

(4) Desalination. The low cost thermal energy can used desalt or otherwise purify water for drinking or irrigation

Multi-flash desalination units along with a solar pond is an attractive proposition for getting distilled water because the multi-flash desalination plant below 100·C which can well be achieved by a solar pond. This system will be suitable at places where portable water is in short supply and brackish water is available. It has been estimated that about 4700m^3/day distilled water can be obtained from a pond of 0.31km^2 area with a multi-effort distillation unit. The cost of distilled water appears to be high for industrialized countries but can be used in developing countries where there is a shortage of potable water. Moreover this type of desalination plant produces five times more distilled water than the conventional basin type solar still.

(5) Heating animal housing and drying crops on farms.

Low grade heat can be used in many ways on farms, which have enough Land for solar ponds. Several small demonstration ponds in Ohio, Iowa and Illinois have been used to heat green houses and hogbarns.

(**6) Heat for biomass conversion**. Site built solar ponds could provide heat to convert biomass to alcohol or methane. While no solar Ponds have been used for this purpose, it is an ideal coupling of two renewable-energy technologies

21. Explain the various Solar Water Heating technology (or Hot Water Supply System). (N/D'13)

The basic elements of a solar water heater are:

(i) Flat plate collector.

(ii) Storage tank.

(iii) Circulation system and auxiliary heating system.

(iv) Control of the system

The Use of *solar* energy for heating water in many respects quite similar to its use for heating building. There are however, several aspects of solar water heating, that make it potentially better investment of energy, money and effort than solar building heating. For one thing, the demand for hot water is relatively constant throughout fuel the year. Thus the collector and other parts of the solar water heater eventually must pay for the higher initial cost of the system. The solar building heating system, on the other hand, fully operational only during the coldest months of the heating season

The simplest type of solar water heater is the thermo siphon system. Some typical and commercial designs of solar water heaters are:

i) Natural circulation solar water heater(pressurized)
ii) Natural circulation solar water heater (non pressurized)
iii) Forced circulation water heater.

Natural Circulation Solar Water Heater (Pressurized)

A natural circulation system is shown' Fig 2.35. it consists of titled collector (south facing), with transparent over glasses, a separate highly insulated water storage tank, and well insulated pipes connecting the two. The bottom of the tank is at least 1 ft(0.3m) the top of the collector, and no auxiliary energy is required to circulate water through it.

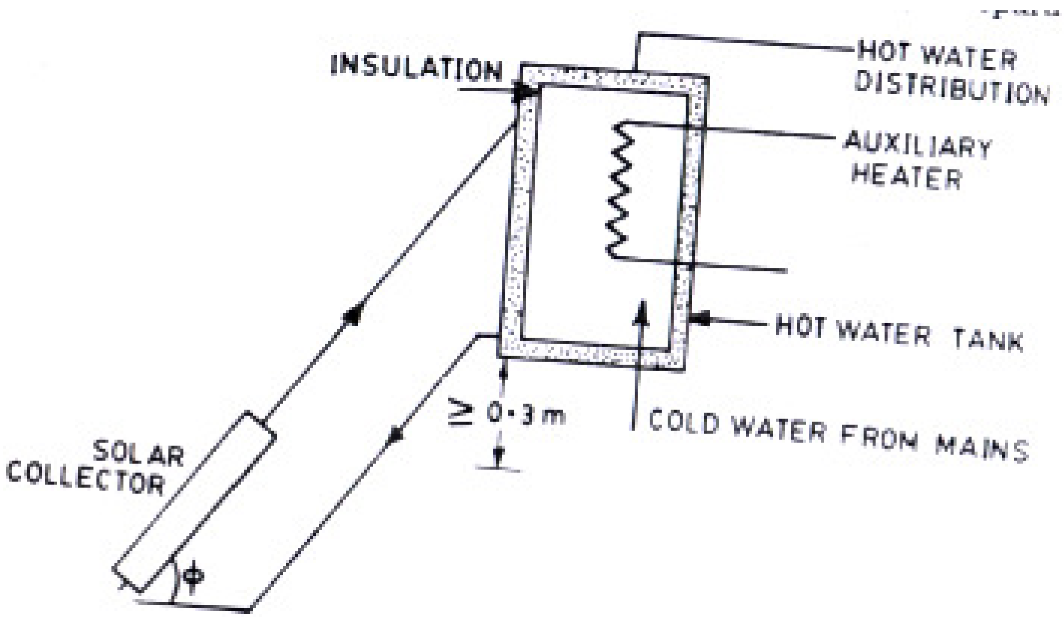


Fig 2.35 Schematic of a natural circulation solar water heater (pressurized)

Circulation occurs through natural convection, or thermo siphoning . As the water is heated in its passage through the collector, its density Decreases and hence it rises and flows into the top of the storage tank, colder water from the bottom of the tank has a higher density and so tends to sink and enter the lower heater of the collector for further heating. The density difference between the hot and cold water thus provides the driving force (convection) for the circulation of water through the collector and the storage tank. Hot water is drawn off from the top of the tank as required and is replaced by cold water from the service system. As long as the sun shines the water will quietly circulates, getting warmer. After sunset, a thermo siphon system can reverse its flow direction and 1055 heat to the environment during the night. To avoid reverse flow, the top heater of the absorber is kept as stated above 0.3 m below the cold leg fitting on the storage tank. To provide heat during long, cloudy periods, an electrical immersion heater can be used as a backup for the solar system. A non-freezing fluid may be used in the collector circuit. The thermo siphon system is one of the least extensive solar hot-water systems and should be used whenever possible. .

Thermo siphon solar water heaters are passive systems and do not require a mechanical pump to circulate the water. Such heaters can be used extensively in rural areas, where electricity is expensive (or not available) and there is little danger of freezing.

(ii) Natural circulation solar water heater (non-pressurized).

The pressurized system is able to supply hot water at locations of the storage tank. This creates considerable stress on the water channels in the collector which must be designed accordingly. The non pressurized systems supply hot water by gravity flow only to users lower than tank. If pressurized hot water is required (for showers, or appliances) the difference in height will have to be' large enough to meet the requirements. If the height of difference cannot be accommodated, the only solution is to install a 'separate pump and pressure tank. The stresses within non-pressurized system are lower which allows cheaper

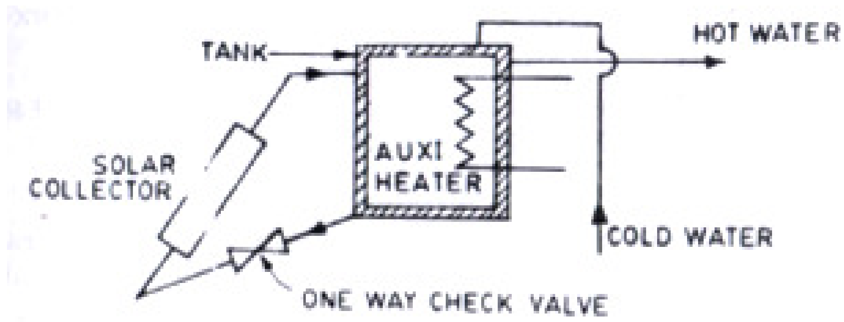


Fig 2.36 Non pressurized solar water heater

End easier construction. In this type also mechanical pump is not required as shown in fig 2.36 however a one way check valve may be desirable to prevent reverse circulation and thus loss of heat at night. A typical system for domestic water heating is shown in fig 2.37

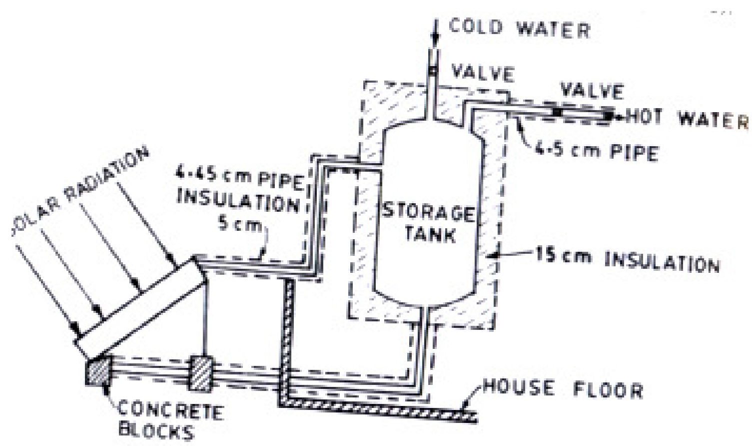


Fig 2.37 Typical solar water heater

iii) forced circulation solar water heater

fig 2.38 shows schematically an example of forced circulation system. By including an electric pump in the return circuit between the bottom of the storage tank and the lower header of the collector, the tank can be placed at a more convective level (e.g in the house basement). This is now an active system. A control unit permits the pump to operate only when the temperature of the water at the bottom of the tank is below that of the water in the upper header.

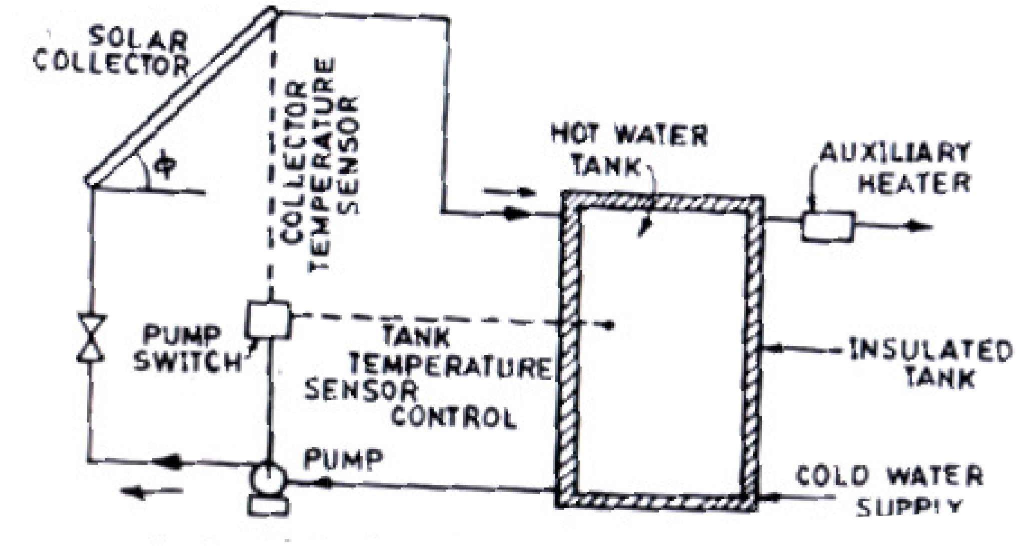
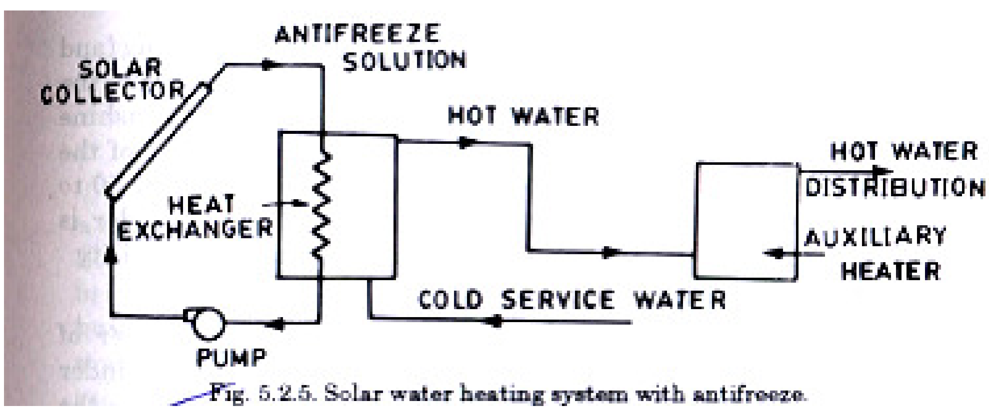


Fig2.38 Schematic of a forced circulation solar water heater

A check valve is needed to prevent reverse circulation and resultant night time thermal losses from the collector. In this example, auxiliary heater is shown as provided to the water leaving the tank and going to the load.

When there is a danger of freezing, the water may be drained from the collector; alternatively, a slow reverse flow of the Warmer water may be permitted through the collector on cold nights. The freezing danger can-be overcome, although at some increase in cost, by using an anti freeze solution as the heat-transport medium, as described earlier. The heat is then transferred to water in the storage tank by way of a heat exchanger coil. (See Fig 2.39)



2.39 Solar water heating system with antifreeze

Space-Heating (or Solar heating of Building)

Many different concepts have been proposed (and tested) for using solar energy in space heating of buildings. There are two primary categories into which virtually all solar heating systems may be divided. The first is p*assive systems* in which solar radiation is collected by some element of the structure itself, or admitted directly into building through large, south facing windows. The second is the *active systems* which generally consists of *(a)* separate solar collectors, which may heat either water or air, *(b)* storage devices which can accumulate the collected energy for use at nights and during inclement days, and, (c)a back up system to provide heat for protected periods of bad weather. Heat is transferred from the collectors or from the storage means by conventional equipment, such as fan coil units, when hot or cold water is provided; fan, ducts, and air outlets, when the heat transfer medium is air; and radiant means when heating is the only task which must be accomplished

Passive heating systems operate without pumps blowers, or other mechanical devices; the air is circulated past a solar heated surface (or surface) and through the building by convection (i.e., less dense, cooler air tends to rise while more dense, cooler air moves downward). In active heating systems, fans and pumps are used to circulate the air and often a separate heat absorbing fluid.

Passive solar thermal systems are more practical in locations where there is ample winter sunshine and an unobstructed southern exposure is possible. The building to be heated is an essential part of the system design. Active systems, on the other hand, can be adopted to almost any location and type of building; however they are more expensive than passive systems to construct and operate. An advantage of active solar systems is that the building air temperature can be controlled in the same way as with the conventional heating, but in most passive systems substantial temperature variations may occur in the course of the day.

In principle, it should be possible to provide all the heating (and cooling) needs of a building by solar energy. However, to do this, the heating system would have to be designed for minimum sunshine conditions and hence would be over-designed for the majority of the situations .In most cases, solar-energy systems provide roughly 50 to 75 per cent 'of the annual heating requirements. The remainder is supplied by an auxiliary-heating systems using gas, oil, or electricity.

Solar Heating Systems

(A) Passive Heating Systems.

An increasing number of residences using various passive systems have been built and are under construction mainly in U.S. Building with large windows facing the equator (South in the northern hemisphere or north in the southern hemisphere) and arranged to admit solar radiation into the building when the sun is low in the winter sky, have been termed 'Solar houses'. The gains to be realized from properly oriented windows are significant, but in cold climates losses during the periods of low radiation, nights and cloudy weather, must be controlled so net gains can be realized.

If a building is designed properly:

(i) It will function as a solar collector, collecting heat when the sun is shining and storing it for later use.

(ii) The building will function as a solar store house. It must store the heat for cool times when the sun is not shining, and store the cool for warm or hot periods when the sun is shining. Buildings which are made of heavy materials such as stone or concrete do this most effectively.

(iii) Building will function as a good heat trap. It must make good use of the heat (or cool) and let it escape only very slowly. This is done primarily by reducing the heat loss of the building through the use of insulation, reduction of infiltration and storm windows.

Wall and roof of the building must be oriented in such a way so as to receive solar radiation heat in the winter and shed it in the summer. A building can benefit from its orientation ; for similar reasons, it also benefit from different ratios of its length to its width to its height. The optimum shape losses, the minimum amount of outward moving heat and gains maximum amount of solar heat in the winter, and retains the minimum amount of solar heat in the summer.

The basic design principles of passive solar space-heating systems, that is, without mechanical components, fall into the following five general categories:

(i) Direct gain

(ii) Thermal storage wall

(iii) Attached sun space

(iv) Roof-storage

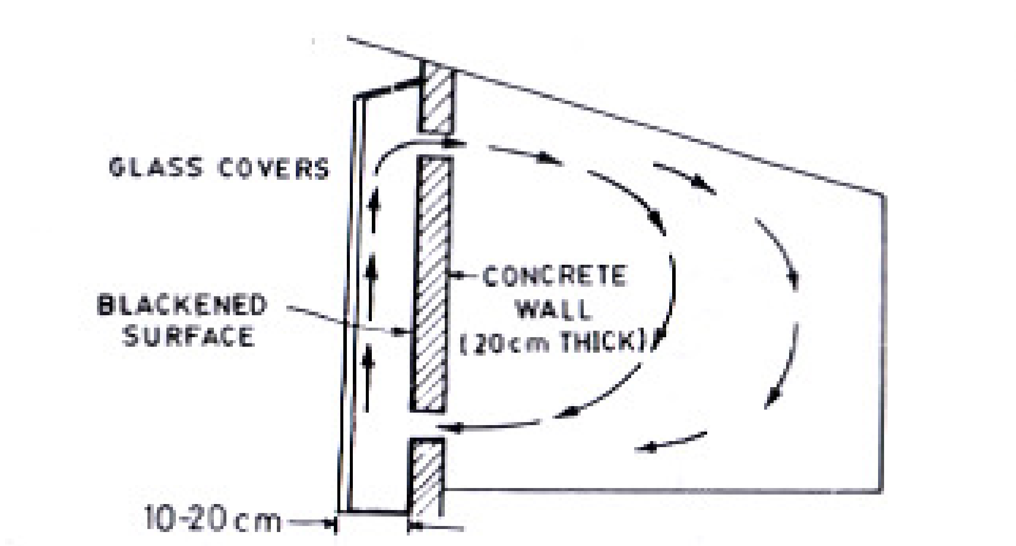
(v) Convective loop.

There are modifications within each of these categories and two or more may be combined in a single building.

Direct gain. In this system, the building has a south wall with a large number of windows; two layers of glass minimize heat losses. Solar radiation entering the windows falls on thick concrete, slate, or brick floors (and possibly walls) and is absorbed and stored as heat. The building air is then heated by radiation and convection from the floor and walls. Covering the windows with shutters or curtains at night reduces heat losses.

Thermal storage wall. A large wall like mass which absorbs solar radiation and stores heat, is placed directly behind large south facing windows. The best known example of the storage wall design is the vertical *Troumbe wall,* made of concrete brick, or other masonry some 0.3 m or more thick. Dr. Felix Trombe, Director of solar energy laboratory at Odeillo (France) has used this principle. The system is passive, because the solar radiation is absorbed by a heavy concrete, south facing wall which is covered with double glazing. A Trombe wall arrangement is outlined in Fig. (2.40). The distance between glazing and concrete wall is about 10 to 20 cm, Concrete, wall is about 20 cm thick, painted black, which serves as both a radiation absorber and a heat storage medium. Heat radiated outward from the wall is trapped by the glass cover, so that the air in between is heated. The heated air rises and enters the adjacent room through vents at the top of the wall, the air circulates by natural convection and is returned by way of ducts at the bottom of the storage wall. Electric strip heaters are provided for standby purposes during excessively cold weather and during days with little sunshine.

Attached sunspace. A sunspace is any enclosed space, such as a green house or sun porch, with a glass wall on the south side. A sunspace may be attached (or built on) to



2.40 passive solar heating system

a thick south wall of the building to be heated by the sun. Vents near the top and bottom of the wall, as ill Fig. (2.40), permit circulation through the main building of the heated in the sunspace. Heat storage is provided by the thick wall, a concrete or masonry floor, water containers, and other materials in the sun space. Thus, an attached suns pace system combines features of direct gain and storage wall concepts.

Roof storage. A passive solar system, trade named Sky Therm, was designed for house having a flat roof located in a mild climate. The heat is absorbed and stored in water about 0.25 m deep contained in plastic bags held in blackened steel boxes on the house roof (Fig. 2.41). In a later design, a layer of clear plastic sealed to the top of the bag provides a stagnant airspace to reduce heat losses to the atmosphere.

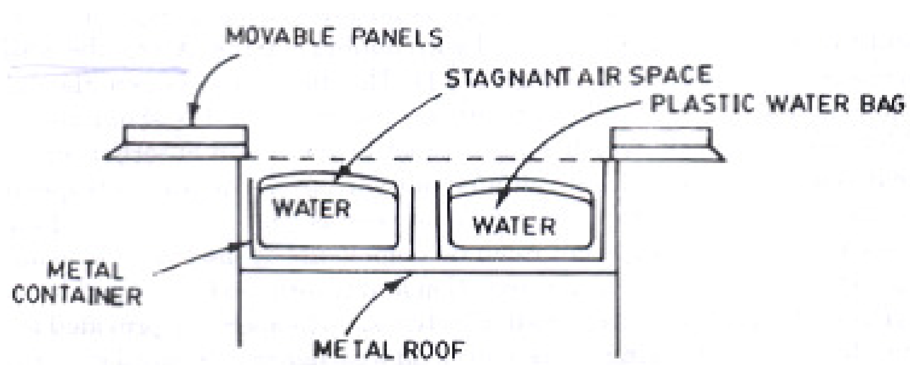
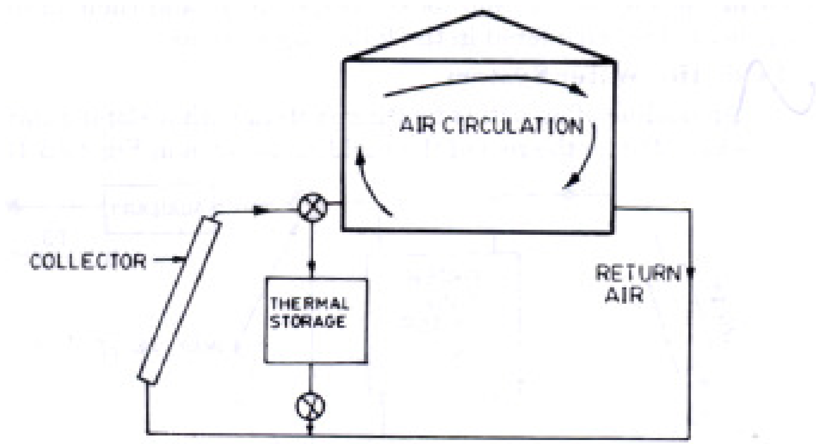


Fig 2.41 Roof storage of solar heat

Heat is transferred from the heated water to the rooms below by conduction through a metal ceiling. Air circulation may be aided by means of electric fans, but this is not essential. To prevent loss of heat during the night, thermal insulator panels are moved, either manually or by a time controlled electric motor, to cover the water bags. In the

day time, the panels, which are in sections, are removed and stacked one above the other.

Convective Loop. In most passive solar space heating systems, the heated air is circulated by convection, but the term convective loop is applied to systems that resemble the thermo siphon hot-water scheme described earlier. Such a convective loop heating system is outlined in Fig. (2.42). It includes a conventional flat-plate collector at a level below



2.42 Convective loop passive solar cooling

that of the main structure. Abed of rock, which may be located beneath a sun space, provides thermal storage. In normal operation, air passing upward through the collector is heated and enters the building through floor vents. The cool, denser air leaving the building returns to the bottom of the collector and is reheated. If more solar heat is available than is required for space heating, the floor vents may be partly (or wholly) closed. The heated air then flows through and deposits heat in the storage bed. Heat stored in this way may be used later, as needed, by transfer to the cooler air leaving the building.

(B) Active Space-Heating Systems. Most of the hundreds of solar-heated residences built throughout the world use the active system, in which separate collectors are used together the solar radiation, transfer it to water or air, and store it in tanks of water or rock piles or both. The water and air are circulated by pumps or fans and conventional means are used to distribute the heat to the interior of the residences.

General Principles. Nearly all existing or proposed active solar space-heating and/or hot-water supply systems utilize three main components in addition to pumps and blowers: (1) a solar radiation collector with its associated heat transport (or heat-transfer) fluid, (2) a heat-storage medium, and (3) a distribution systems. The same arrangement of components can also be used to provide hot water for domestic and related use and, with the addition of other components, space cooling (air conditioning). In the collector the solar radiation is collected and converted into heat. The heat-transport fluid removes the heat and carries it to the heat-storage system; the heat can then be withdrawn from the storage and distributed throughout the building. Schematics of basic hot water and hot air heating systems are given in the Fig. (2.42) respectively and their individual components are considered in the following sections.

(1) Basic Hot Water System

An outline of an active heating system with a sloping flat plate collected located on the roof of the building is given in Fig. (2.42). This

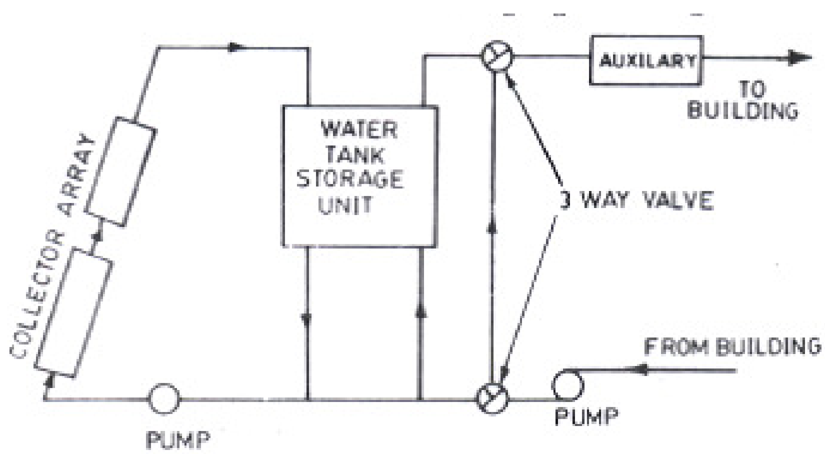


Fig 2.42 Schematic of a basic hot water active system

is a basic *hot water heating* system, with water tank storage and auxiliary energy source. Heat is transferred to the water in the storage tank, commonly located in the basement of the building. The solar heated water from the tank passes through an auxiliary heater, which comes on automatically when the water temperature falls below a prescribed level. For space heating, the water may be pumped through radiators or it may be used to heat air in a water to air heat exchanger.

During normal operation, the three way valves are set to permit solar heated water to flow from the storage tank and auxiliary heater to the distribution system and back to the tank. If after several cloudy days, the heat in storage is depleted, the valves will adjust automatically to bypass the storage tank. In this way, auxiliary heating of the large volume of water in the tank is prevented. If the temperature in the heater at the top of the collector should fall below that at the bottom of the tank, the pump (at bottom left of figure) would be switched off automatically.

If in this system, the heat transport medium is an antifreeze solution, then there is a closed circuit of it, with the heat exchanger coil in the storage tank. This type of solar space heating system with hot water system is shown in Fig. (2.43)

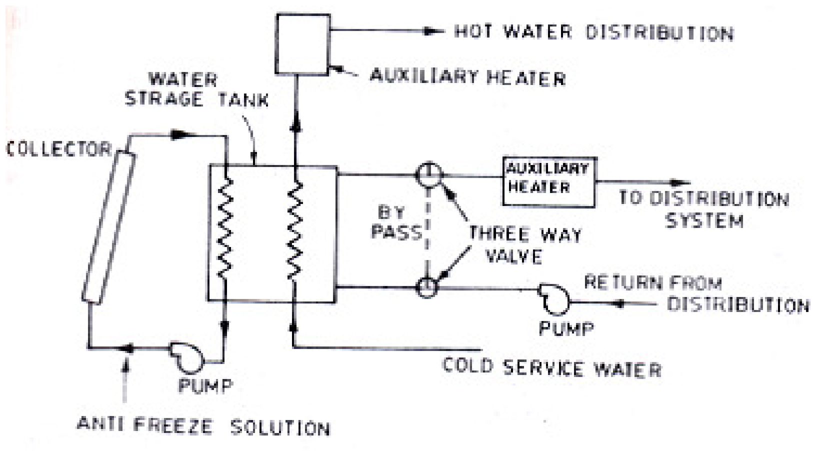


Fig 2.43 Solar space heating and hot water system

Advantages and disadvantages of basic hot water system are listed below**:**

Advantages

(i) In case of water heating, a common heat transfer and storage medium, water is used, this avoids temperature drop during transfer of energy into and out of the storage.

(ii) It requires relatively smaller storage volume.

(iii) It can be easily adopted to supply of energy to absorption air conditioners, and

(iv) Relatively low energy requirements for pumping of the heat transfer fluid.

Disadvantages

(i) Solar water heating system will probably operate at lower water temperature than conventional water systems and thus require additional heat transfer area or equivalent means to transfer heat into building.

(ii) Water heaters may also operate at excessively high temperatures (particularly in spring and fall) and means must be provided to remove energy and avoid boiling and pressure build up.

(iii) Collector storage has to be designed for overheating during the period of no energy level.

(iv) Care has to be taken to avoid corrosion problems.

(2) Basic Hot Air System

Schematic diagram of a basic hot air heating system is shown in Fig. (2.44). In this system the storage medium (pebbles or rock) is held

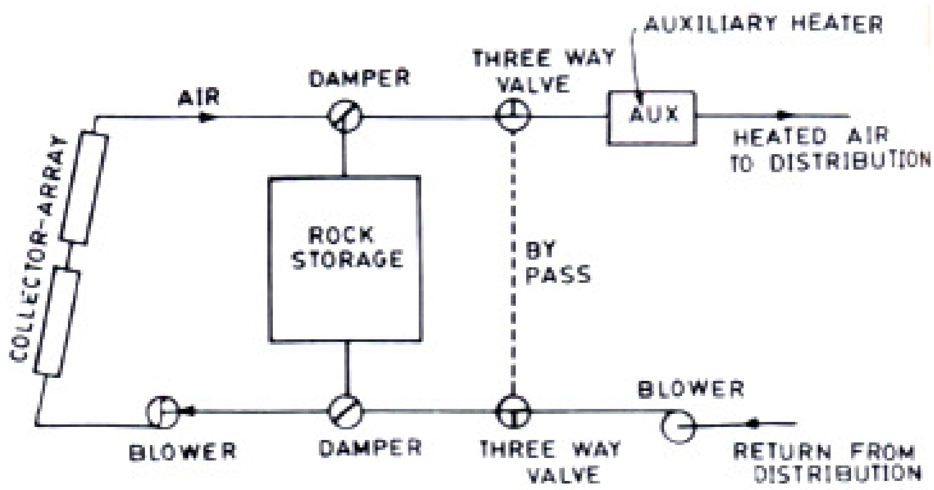


Fig 2.44 Schematic diagram of a basic hot air heating system

in the storage unit, while air is the fluid used to transport energy from collector to the storage and to the building. By adjusting the dampers, the heated air from the collector can be divided between rock storage and the distribution system, as might be required by the conditions. For example" when the sun shines after several cloudy days it would be desirable to utilize the available heat directly in the distribution system rather than placing it in storage. Two three way valves can be used to bypass the storage tank, as explained above. An auxiliary source of heating is also provided. Auxiliary heating can be used to augment the energy supply to the building from the collector or storage if the supply of heat from it is inadequate.

The position of the blower in figure is shown at the upstream of the collector and the storage, and it forces the air through these for heating. In this case slight leakage of heated air will take place. Blower can also be placed on the downstream side of the collector and storage, so that the pressure in the collector is not above ambient pressure, which might be advantageous in controlling leakage.

System based on this concept has number of ***advantages***, compared with those based on use of water as a heat transfer medium.

(i) There is no problem with freezing in the collectors.

(ii) Corrosion problems are minimized.

(iii) Conventional control equipment for air heating is already available and can be readily used.

(iv) Problems of designing for overheating during periods of no energy removal are minimized, and,

(v) The working fluid is air and the warm air heating systems are ill common use.

Disadvantages of air heating system are :

(i) Relatively higher power costs for pumping air through the storage medium.

(ii) Relatively large volumes of storage units.

(iii) Difficulty of adding absorption air conditioners to the system.

Collectors and Heat Transport. Because of their simplicity, fixed position, flat-plate collectors are almost invariable used in space heating applications of solar energy. Since they can collect diffuse as well as direct solar radiation, flat-plate collectors are partially effective even when the sun is not shining. Either air or water can be used as the heat-transport fluid. The plumbing system is less likely to have problems in a system using air, but larger ducts and a larger heat storage volume are required.

Many types of flat-plate collectors are available. As a general rule, these collectors are fabricated in panels, commonly about 6 to 8 ft (1.8 to 2.4 m) long and 3 to 4 ft (0.9 to 1.2 m) wide. The number of panels (or the total collector area) depends on the space to be heated (or cooled) and the local climate, as well as on economic factors. In new home construction, the panels are mounted on a roof facing south (or south southwest) with the optimum slope *te.gs}* latitude + *15*° for heating). Otherwise, the panels with the required slope may be placed on the ground or on a flat roof, if one is available. The panels must then be spaced in such a manner that they do not shade one another significantly when the sun is low in the sky.

An essential piece of information for the design of a collector for space heating is the daily insolation, that is, the total amount of direct and diffuse solar radiation energy received per day on a horizontal surface of unit area on the ground. For a surface inclined at an angle to the horizontal equal to the latitude + *15°,* the solar radiation received is higher in winter and lower in summer.

From knowledge of the daily temperatures throughout the year, it is possible to determine the amount of thermal energy (heat) required for space heating in the winter and cooling in the summer. By using the daily insolation at the given location, an estimate can then be made of the area of a flat-plate collector, sloping at a prescribed angle, that will supply a certain proportion of the heat required.

The degree (or percentage) of dependence on solar energy for which a collector system is designed is determined by balancing the cost of the collectors against the estimated future costs of alternative energy sources. It is the future rather than the present costs that are important in this respect. The higher the expected cost of an alternative energy supply, the larger the economically acceptable collector area. Thus in deciding on this area, the local climatic and economic factors must be considered. Furthermore, the collector area should be proportional to the area of the building to be heated (or heated and cooled). A very rough rule for moderately cool climates is a collector area about 50percent of the floor area.

Heat Storage. A means for storing heat is necessary in active solar energy systems to supply heating requirements during the evening and on cloudy days. The larger the heat-storage volume, the greater is the heat-storage capacity for a given material and the longer the sunless period for which heat could be available. But increasing the volume means increasing the cost and space requirements. As a compromise, heat storage tanks are generally designed to have a heat capacity equivalent to three days normal demand. The common heat storage materials are water and small pieces of rock. When water (or an antifreeze solution) is used as the heat transport fluid in the collector, a large, well-insulated tank of water provides the heat storage. The water may be pumped directly from the collector through the storage tank. It may pass through a heat exchanger coil in the tank when the heat-transport liquid contains an antifreeze compound *i.e.,* ethylene glycol).

If air is the heat-transport medium, the heat is usually stored in pieces of rock or pebbles, roughly 2 in. (5 cm) across, contained in an insulated tank through which the air circulates. The efficiency of transfer of heat from the hot air to the rock pieces is greater for smaller sizes of the pieces. With decreasing size, however, the resistance to air flow increases and more pumping power is required to circulate the air. The selected size thus l'e presents a compromise between two opposing factors.

A given volume of water can store substantially more heat than an equal volume of rock, assuming the same temperature increase in each case. Thus, water can store 4100 kilo joules per cubic meter per °C increase in the temperature on the other hand, the rock can store roughly 1460 KJ per cu m per "C, where the volume includes allowance for the spaces between the rock pieces. Hence, for the same heat storage, rock would occupy about three times the volume of water.

The following data provide an approximate guide to the relationship between the storage volume and the area of the flat plate solar collector for water and rock storage:

Water: 0.05 to 0.075 m^3 per m^2

Rock : 0.17 to 0.02 m^3 per m^2.

These numbers are average values for different climatic conditions ; both smaller and larger volumes have been used in special circumstances.

If a home with a floor area of 150 sq. m (1600 sq. ft) has a solar collector areaof85 sq. m (915 sq. ft), the storage volume of water would be in the range of 4.2 to 6.3 cum (150 to 225 cu ft), whereas for rock, it would be 14 to 21 cum (500 to 750 cu ft). The larger volume in each case' would be desirable in a colder climate.

A considerable increase in heat-storage capacity, with a corresponding decrease in volume, could be achieved by using a suitable salt-hydrate, instead of water or air, as the storage medium. A salt hydrate is a salt in which the solid crystals include a number of water molecules. Special interest has been focused on the relatively inexpensive salt-hydrate sodium sulphate decahydrate (Na2S04, 10H20), commonly known as Glauber's salt.

When heat is added to the salt, the temperature increases to 32°C, called the transition point, At this point, the temperature remains constant while the salt changes to an aqueous solution plus solid Na2S04 *(i.e.* without the water molecules) ; during this stage heat is stored, although the temperature does not rise. When all the Na2S04 10 H20 has been changed to

Na2S04, the temperature can increase again as more heat is added. If heat is withdrawn from the system, the temperature falls to 32°e, where it remains while the stored heat is released and the Na2S04 10 H20 is completely regenerated; thus,

$$NO_2SO_4\,10\,H_2O \underset{\text{Heat withdrawn at } 32^\circ C}{\overset{\text{Heat supplied}}{\rightleftharpoons}} Na_2SO_4\,(\text{solid}) + H_2O\,(\text{solution})$$

Salt-hydrate heat storage has been tested in solar heating systems with air as the transport medium. The salt was contained in a number of stacked 5-gallon (19 litre) cans around which the air was circulated. The systems operated well for a time but gradually deteriorated.

The reason was that as the solid Na2S04 formed (from the Na2S0410 H20), it tends to deposit on the walls of the storage cans. As a result, the reverse process, in which the Na2S04 10 H20 is regenerated from the Na2S04, did not occur completely. Hence, the storage capacity decreased as the system was operated. Furthermore, the solid deposited on the walls decreased the heat transfer efficiency. A possible means of overcoming both of these difficulties is by slow rotation of a drum containing the salt hydrate, the solid Na2S04 formed would then remain in suspension in the solution**.**

Heat distribution. The distribution system for solar space heating is much the same as for any other heat source; in fact, existing systems for the gas or oil heat have been readily adopted, to solar heating.

When water is the heat-transport, fluid, it may be circulated through radiators in the building to be heated, and then back to the storage tank. Alternatively, a water to air heat exchanger can serve to heat air for distribution by way of conventional heating ducts. The air is blown (or drawn) across a pipe coil (heat exchanger) through which the hot water flows (Fig 2.45). In a modification of this system, transfer of heat from hot water to air is achieved by passing the air through a container of rock pieces surrounding the storage tank.

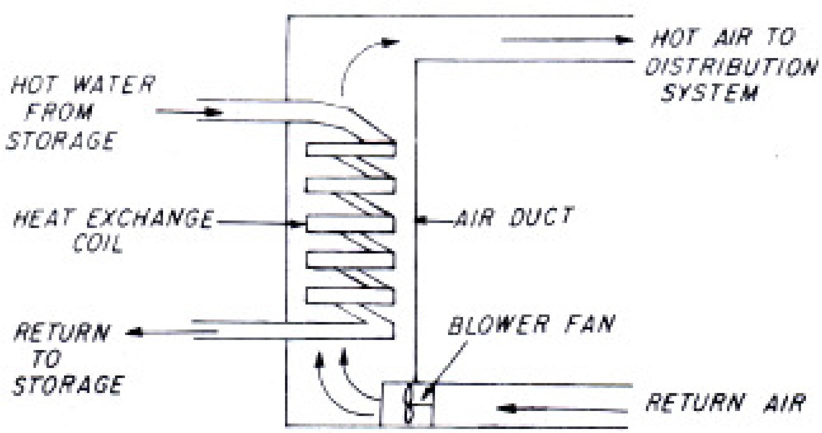


Fig 2.45 Water –to-air heating system

If air is the heat-transport fluid (with rock or salt-hydrate storage), the heated air can be circulated through the building and back to the storage system. The building space is then part of a closed circuit.

Solar Distillation

22. Write short notes on Solar Distillation with neat sketch.

Fresh water is a necessity for the sustenance of life and also the Key to man's prosperity. It is generally observed that in some arid, semiarid and coastal areas which are thinly populated and scattered, one or two family members are always busy in bringing fresh water from along distance. In these areas solar energy is plentiful and can be used (or converting saline water into distilled water). The pure water can be obtained by distillation in the simplest solar still, generally known as

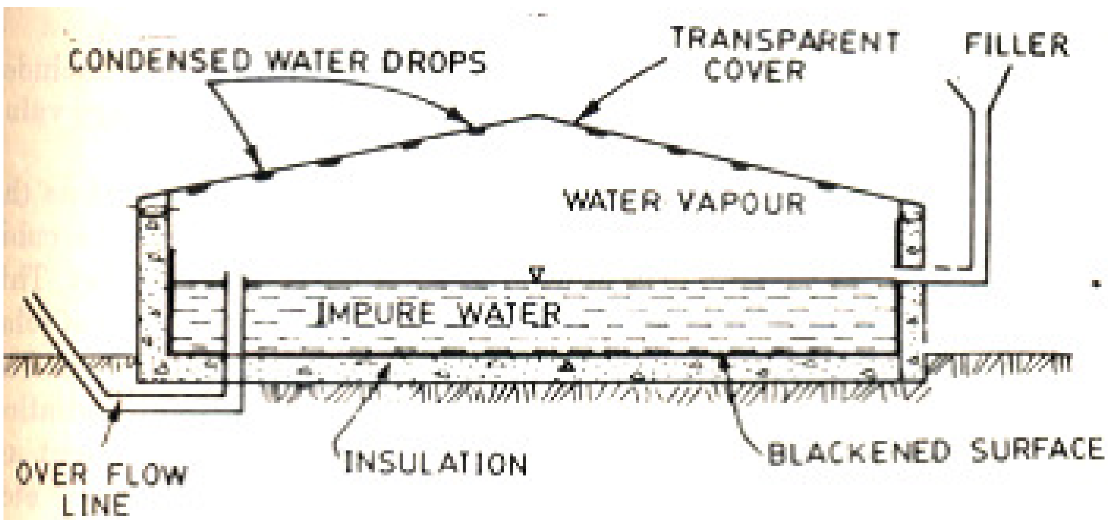


Fig 2.46 Solar water still

the ''basin type solar still". It is shown schematically in Fig. (2.46).solar stills have been operated for farm and community use in several countries. It consists of a blackened basin containing saline water at a shallow depth, over which is a transparent air tight cover that encloses completely the space above the basin. It has a roof-like shape. The cover, which is usually glass, may be of plastic, is sloped towards a collection trough. Solar radiation passes through the cover and is absorbed and converted into heat in the black surface. Impure water in the basin or tray is heated and the vapour produced is condensed to purified water on the cooler interior of the roof. The transparent roof material, (mainly glass) transmits nearly all radiation falling on it and absorbs very little; hence it remains cool enough to condense the water vapour. The condensed water flows down the sloping roof and is collected in troughs at the bottom. Saline water can be replaced in the operation by either continuous operation or by batches. Although there are numerous configurations of basin type units, their basic theory is identical.

The basin type solar still has produced distilled water at a cost per unit of product lower than other types of solar equipment and is the only type in operation. Operating efficiencies of

35 to 50%for basin type still have been achieved in practical units, as compared with a theoretical maximum of slightly more than 60%.

The performance rating and efficiency of the solar still is determined by plotting the graph of the amount of fresh water produced per unit of basin area in one day versus the solar radiation intensity over the same period. Such curves for several stills are drawn. Efficiency defined as

$$\eta = \frac{w\Delta h}{H}$$

Where w = weight of distillate per square meter per day.

Δh = enthalpy change from cold water to vapour.

H = Solar radiation intensity per square meter per day.

Here area of the water surface is to be considered. Sh. Includes the latent heat of vaporization, which is being taken as average value 594.5 kcal/kg (2489 kJ/kg).

The performance of a solar still is generally expressed as the quantity of water produced by each unit of basin area in a day i.e. cubic meters of litres of water per square meter of basin area per day. This quantity will vary with the design of the still, with the intensity of solar radiation and with the atmospheric conditions in the surroundings. The production rate depends primarily on the amount of solar radiation available but is affected by several other factors ; like ambient air temperature, wind speed, atmospheric humidity, sky conditions etc the effect of design parameters such as orientation of still, single sloped or double sloped, inclination of glass cover, insulation of the base etc., and the effect of operating parameters such as water depth in the tray, absorption emittance properties of the still, preheating of water etc. Solar still installations may provide about 15 to 50 litres per day per 10 sq. m.

Solar Drying

23. What are the functions of Solar Drying Technology and its types?

Solar drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other agricultural, forest products. In order to benefit from the free and renewable energy source provided by the sun several attempts have been made in recent years to develop solar drying mainly for preserving agricultural and forest products. However, for large-scale production the limitations of open-air drying are well known. Among these are high labour costs, large area requirement, lack of ability to control the drying process, possible degradation due to biochemical or microbiological reactions, insect infestation, and so on. The drying time required for a given commodity can be quite long and result in post-harvest losses (more than 30%)

It may be classified as three categories

- Open Sun Drying
- Direct solar drying
- Indirect solar drying

1. Open Sun Drying:

The working principles of open sun drying system are shown in fig.2.47 it is simplest system still widely used in rural parts of our nation. In this system the crops are spread on the open surface area where there is direct sun light.

The short wavelength solar radiation falls n the uneven crop surface. A part of this energy is reflected back. The remaining part is absorbed by the crop surface depending upon the color of the crops. The absorbed radiation is converted into thermal energy. Due to this the temperature of the crop starts increasing. It results the long wavelength radiation and convective heat loss due to blowing wind losses from the surface of crop to ambient air. The crop is dried due to evaporation losses. Further, a part of the absorbed thermal energy is conducted into the interior of the product. It causes a rise in the temperature of the crop and further drying.

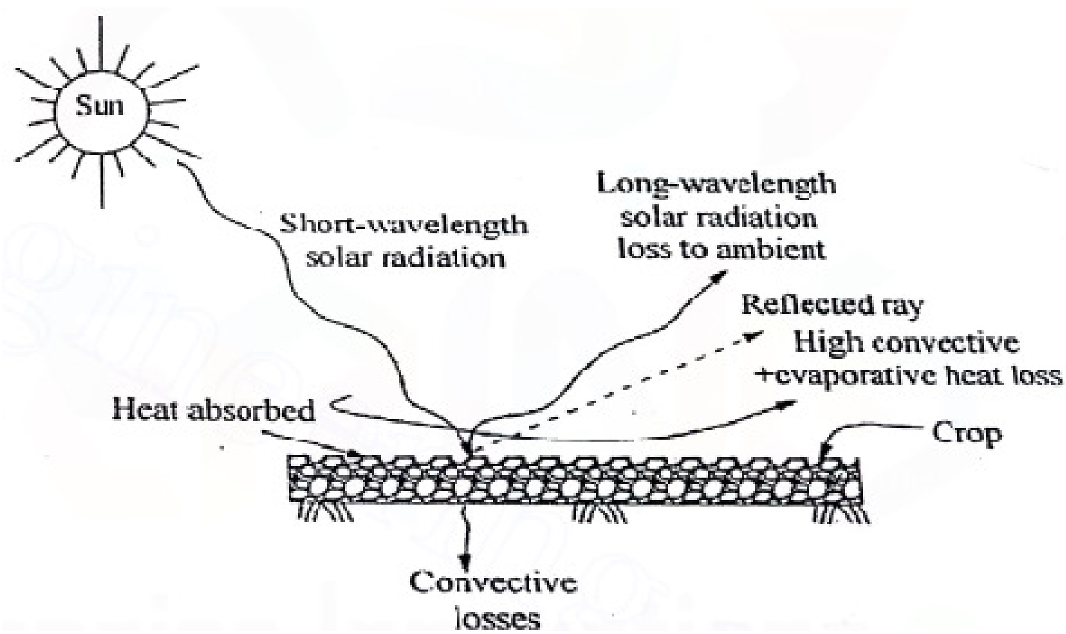


Fig2.47 Open sun crop drying

In this type of drying, there is a considerable loss due to various reasons such a rodents, birds, insects and micro organisms. The unexpected rain or storm further worsens the situation. Further, there may be a possibility of over drying, contaminants of foreign materials such as dust, and insects.

2. Direct solar drying

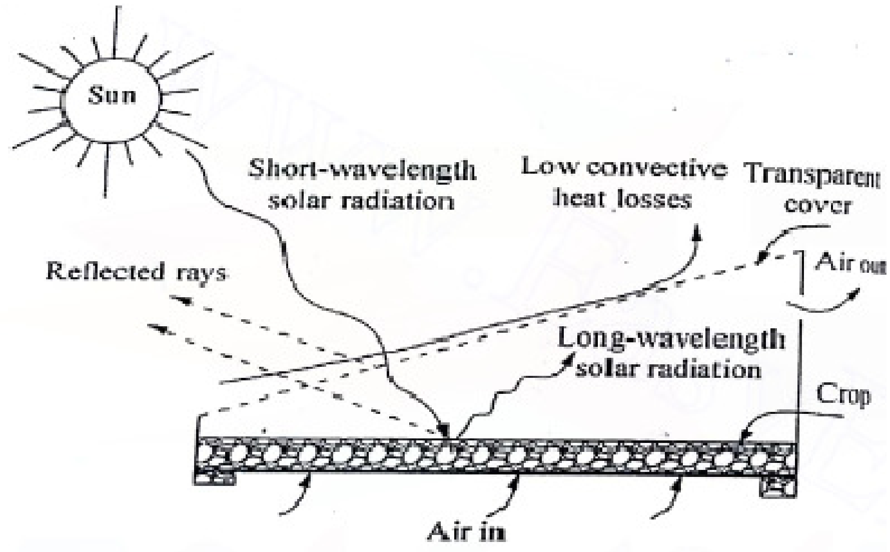


Fig 2.48 Direct solar crop drying

The working principles of direct solar drying system are shown in fig 2.48 it is referred to as a cabinet dryer. In this system, the crops are spread inside the chamber base having metallic net frame which is covered by a transparent glass cover. An air vent is provided n side of the chamber to facilitate escape f hot air and moisture. A part of the incident solar radiation on the gas cover is reflected back to the atmosphere. Remaining part f the solar radiation is transmitted through the glass cover inside the cabinet dryer. Further, a part of transmitted radiation is reflected back from the surface f the crop. Due t the absorption of solar radiation , the crop temperature increases and the crop starts emitting long-wavelength radiation that is not allowed to escape to atmosphere due to the presence of the glass cover, unlike open sun drying. Thus, the temperature above the crop inside chamber becomes higher.

3. Indirect solar drying

The working principle of indirect solar drying system is shown in fig 2.49 In this system, the crop is not directly exposed to solar radiation to minimize the discoloration and cracking on the surface of the crop. A separate unit termed a solar air heater is used for crop heating by allowing hot air into the drying chamber. The hot air is allowed to flow through the wet crop. The drying is basically achieved by the difference in moisture concentration between drying air and air at the vicinity of crop surface.

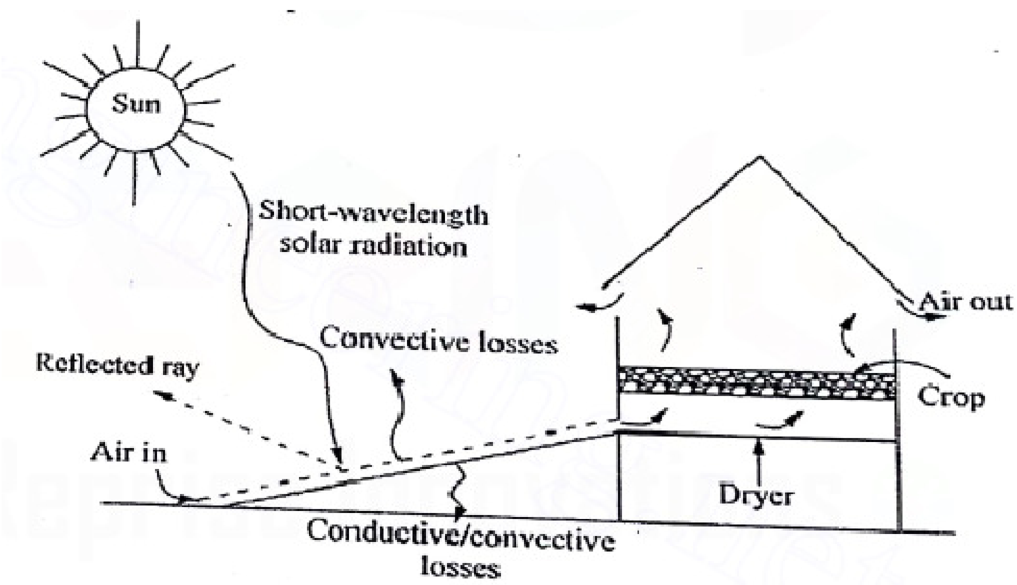


Fig 2.49 Indirect solar crop drying

Solar thermal energy storage

24. State the various classifications of solar energy methods and applications.

The actual and proposed applications of solar energy may be considered in three general categories:

(a) Direct Thermal Application make direct use of heat, resulting from the absorption of solar radiation, for space heating (and cooling) of residences and other building, so provide 'hot water service for such, and other buildings, and to supply heat for agricultural industrial, processes that require only moderate temperatures.

(b) Solar Electric Applications * are those in which solar energy is converted directly or indirectly into electrical energy. Four general conversion methods are being investigated:

(i) Solar thermal methods involve production of high temperatures, such as are required to boil water or other working fluid for which drive electric operating turbines which drive electric generators. These are considered under solar thermal electric conversion.

ii) Photovoltaic methods make use of devices(solar cells) to convert solar energy directly into electrical energy without machinery

iii) The conversion of solar energy into electrical energy without use of machinery, by utilizing thermal electric effect, is also considered as thermo electric conversion

iv)Wind energy is the form of solar energy that can be converted into mechanical (rotational) energy and hence into electrical energy by means f generator. This indirect use of solar energy to generate electricity is described under the chapter of wind energy

Ocean thermal energy conversion depends on the difference in temperature between solar heated surface water and cold deep ocean water to operate a vapor expansion turbine and electric generator. This indirect use of solar energy is considered in chapter ocean thermal energy conversion

(c) Energy from Biomass and Bio-gas, refers· to the conversion into clean fuels or other energy related product of organic matter derived directly or indirectly from plants which use solar energy to grow. Biomass materials include agricultural, forest, and animal 'residues, as well as terrestrial and aquatic plants grown especially for the purpose. For a detail discussion see chapter on Biomass and Biogas.

Solar energy is a time dependent and intermittent energy resource. In general energy needs or demands for a very wide variety of applications are also time dependent, but in an entirely different manner from the solar energy supply. There is thus a marked need for the storage of energy or another product of the solar process, if the solar energy is to meet the energy needs. This problem is specially severe for solar energy when it is used for beating in winter, because of its low availability during this period.

The need for energy storage of some kind is almost immediate evident for a solar electric system. An optimally designed solar-electric system will collect and convert when the insolation is available during the day. Unfortunately the time when solar energy is most available will rarely coincide exactly with the demand for electrical energy, though both tend to peak during the day light hours. There is also the problem of clouds with photovoltaic plants, and cloud cover for several days may result in substantially lowered electrical output compared to high insolation cloud-free days. Obviously during such days energy previously stored during high insolation times could be used to provide a continuous electrical output or thermal output. Thus the addition of

Storage can increase the reliability of being able to deliver power at an arbitrary needed time.

Storage of solar energy in a solar system may:

1. Permit solar energy to be captured when insolation is highest and then later used when the need is greatest. It can thus transform a diurnal solar energy input into a more uniform desired electrical of thermal output.

2. Make it possible to deliver electrical load power demand during times when insolation is below, normal or non-existent. Storage also makes it possible to deliver short peaks of power for exceeding the rated power capacity of the plant.

3. be located close to the load, thereby minimizing the need for costly transmission and distribution facilities which would otherwise be required to meet peak load demands when storage not present there.

4. Improve the reliability of the solar thermal as well as solar electric system

5. Permit a better match between the solar energy storage input and the load demand output than would be the case without storage.

The optimum capacity of an energy storage system depends in general, on the case without storage on the following factors:

(i) The expected time dependence of solar radiation availability.

(ii) The nature of loads to be expected on the process.

(iii) The degree of reliability needed for the process.

(iv) The manner in which auxiliary energy is supplied

(v) The size of the solar thermal power system or solar-electric generator

(vi) The cost per kWH of the stored energy.

(vii) The permissible capital cost allocated to storage.

(viii) Environmental and safety considerations.

(ix) An economic analysis that determines how much of the total usually annual loads should be carried by solar and how much by auxiliary energy sources. .'

Energy storage may be in the form of sensible heat of solids or liquid medium as heat of fusion in chemical systems or as chemical energy of products in the reversible chemical reaction.

Mechanical energy can be converted to to potential energy and stored in the elevated fluids. Product of the solar processes other than energy may be stored in tanks until needed

The choice of media for energy storage depends on the nature of process. For water heating, energy storage as sensible heat of stored water is logical. If air heating collectors are used, storage is sensible or latent heat effects in particular storage units are indicate, such as sensible heat in a pebble bed heat exchanger. If photovoltaic or photo chemical processes are used, storage mostly logical in the form chemical energy or energy is stored in the batteries. Thus the energy may be stored in a variety of forms, e.g., as heat, electrical, chemical, mechanical and magnetic.

Solar Energy Storage Systems

Energy storage systems may be broadly classified (Fig 2.50) as under

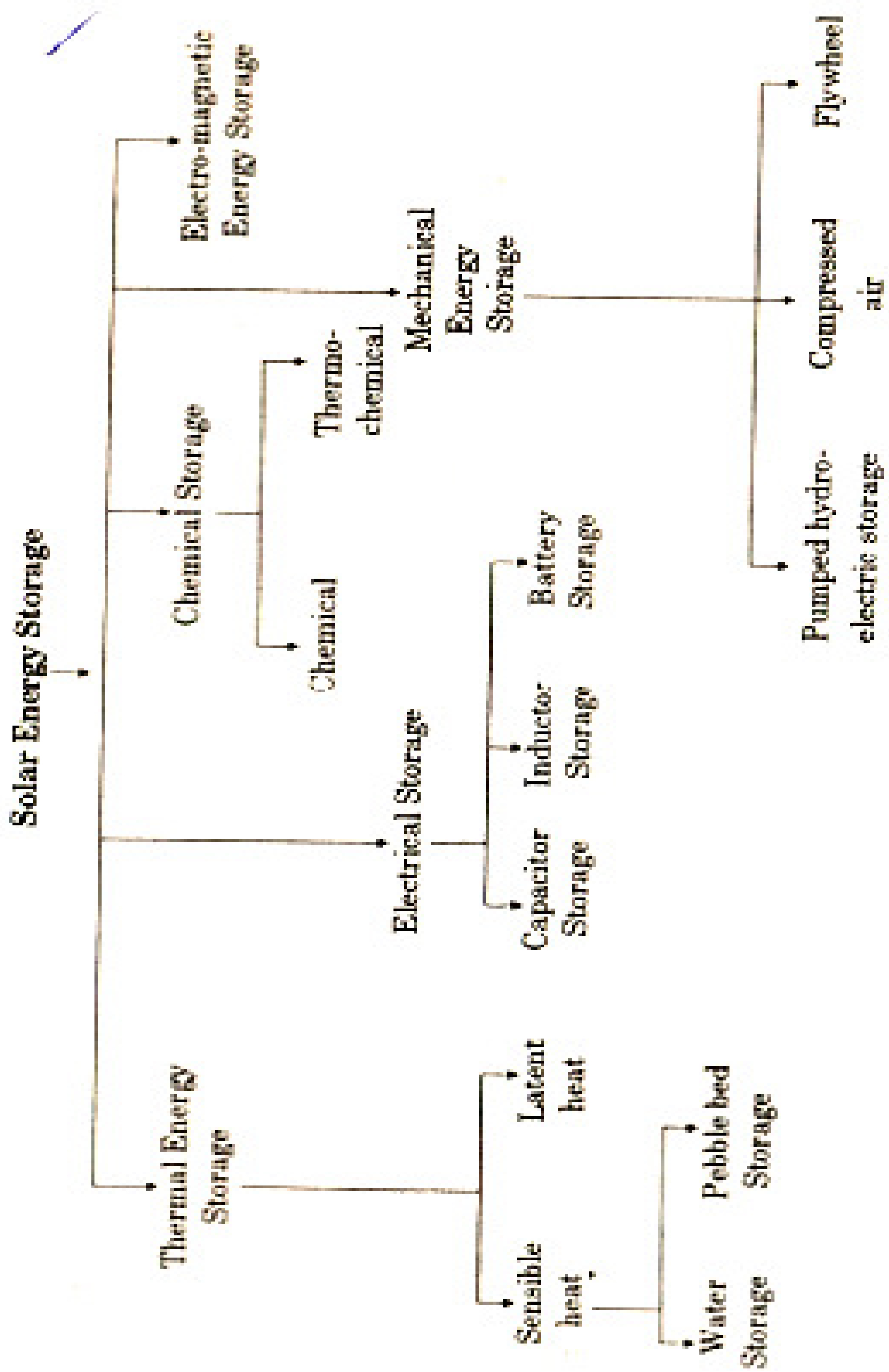


Fig 2.50 classification of solar energy storage

1. Thermal Storage

Energy can be stored by heating, melting or vaporization of material and the energy becomes available as heat, when the process is called sensible heat storage by causing material to rise in temperature is called sensible heat storage. Storage by phase change, the transition from solid to liquid or from liquid to vapour is another thermal storage, known as the latent heat storage, in which no temperature change is involved: It is possible for both sensible and latent heat storage to occur in the same materials. As when solid is heated then melted, then raised further in temperature.

Thermal energy storage is essential for both domestic water and space heating applications and for the high temperature storage systems needed for thermal power applications. Storage is also required in the process of industries and horticultural. The choice of the storage material depends on the particular application and for many domestic applications, water and/or rock storage systems have been developed rock are typical examples of material which store energy as heat (sensible heat), but their use is limited by their comparatively low specific heats. The heat of fusion (latent heat) which is when a substance changes state from a solid to a liquid provides an attractive method of storing a given amount of heat within a much smaller volume. Glauber's salt (Na_2, $S0_4$ $10H_20$) is the least and most readily available salt hydrate. For high temperatures storage in the order of 200 to 300°C other salts have been used and. the heat of hydration of inorganic oxides principally MgO and CaO.

(a) Sensible heat storage.

Sensible heat storage involves materials that undergo no change in phase over the temperature domain encountered in the storage process. The basic equation for an energy storage unit, operating over a finite temperature difference is :

$$Qs = (m\ Cp)s\ (T_1 - T_2)$$

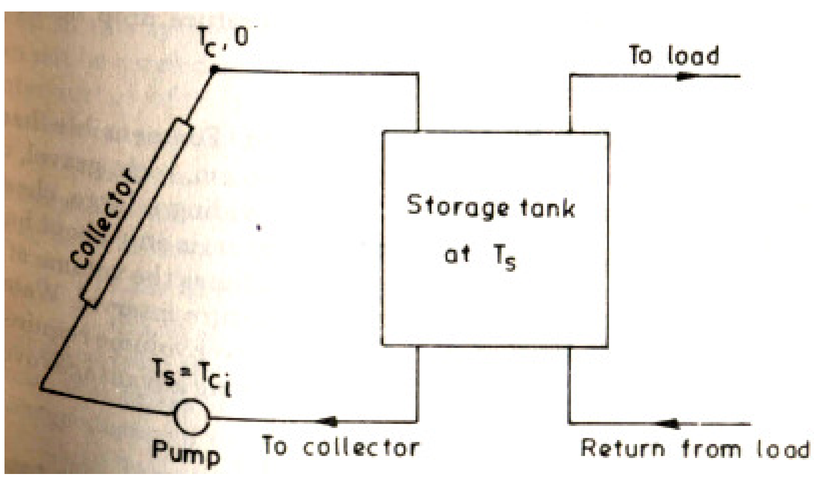


Fig 2.51 Water tank storage unit. Energy is added by circulating water through collector and is removed by circulating water through load

where Q_s is the total thermal energy capacity for a cycle operation between temperature limits T_1 and T_2 with m kg of storage medium of specific heat Cp. The temperature range over which such a 'system can operate is limited at the lower extreme by the requirements Of the process, and the upper limit by the process of the vapour pressure of the liquid. The ability of store thermal energy in a given container of volume V is,

$$Q_{S/V=\rho} C_P \Delta T$$

where p is the density of the storage medium.

Thus the ability to store heat depends upon the product p C_P water has the highest value, but other materials have low values. Materials which are generally used for this type of storage are (i) Water (ii) Rock, gravel or crushed stone, (iii) Iron shot (iv) Iron, red iron oxide or iron ore (magnetic), (v) Concrete, (vi) Refractory materials like magnesium oxide, aluminium oxide (alumina) and silicon oxide.

(A) Water storage.

The most common heat transfer fluid for solar system is water, and the easiest way to store thermal energy is by storing the water directly in a well insulated tank. The optimum tank size for flat-plate collector system is usually about 70 kg/m^2 (2 gal/ft^2). Water has the following characteristics for storage medium

(i) It is an inexpensive, readily available and useful material store sensible heat.

(ii) It has high thermal storage capacity.

(iii) Energy addition and removal from this type of storage is done by medium itself, thus eliminating any temperature drop between transport fluid and storage medium

(iv) Pumping cost is small.

(B) Packed bed exchange storage

For sensible heat storage with air as the energy transport mechanism, rock, gravel, or crushed stone in a bin has the advantages of providing a large, cheap heat transfer surface. Its thermal capacity, however, is only about half that of water, and the bin volume will be about 3 times the volume of a water tank, that is heated over the same temperature interval. Water is superior because of its lower material cost and lower volume required per unit of energy stored. Rock does have the following advantages over water

1 rock is more easily contains than water.

2. Rock acts as its wn heat exchanger, which reduces total system cost.

3. It can be easily used for thermal storage at high temperatures, much higher than the 100^0c; storage at high temperature where water cannot be used in liquid form without an experience, pressurized storage tank.

4. The heat transfer coefficient between the air and solid is high.

5. The cost of storage material is low

6. The conductivity of the bed is low when air flow is not present.

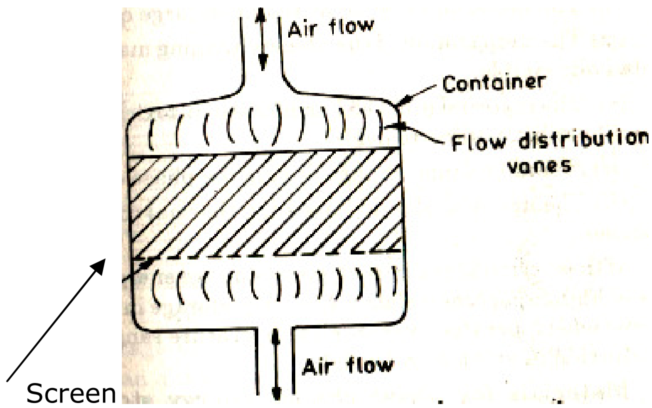


Fig 2.52 Schematic of packed bed storage unit.

A packed bed storage unit is shown schematically in fig 2.52 which uses the heat capacity of abed of closely packed particulate material through which fluid, usually air is circulated to add or remove heat from the bed. Essential features of a packed bed storage unit are a container, porous structure to support the bed and air distributors. In operation the flow is maintained through the bed is one direction during addition of heat and in the opposite direction during the removal of heat. In this system, the heat addition and removal from the storage cannot be carried out simultaneously. Insulation requirements at the outer surface of the packed bed are minimal, for short term storage, as the thermal conductivity in the radial direction is low.

Pebble bed exchanger has good heat transfer characteristics between air and the solids of the bed. This type of storage has been used in the solar houses or with hot air collector system

(b) Latent heat storage (phase change energy storage)

In this system, heat is stored in a material when it melts and extracted from the material when it freezes. Materials that undergo a change of phase in a suitable temperature range may be useful for energy if the following criteria can be satisfied:

(i) The phase change must be accompanied by high latent heat.

(ii) The phase change must be reversible over a very number of cycles without degradation.

(iii) The phase change must occur with limited super cooling

(iv) Means must be available to contain the material and transmit heat into it and out of it.

(v) The cost of materials and its containers must be reasonable.

(vi) Its phase change must occur close to its actual and by melting temperature.. .

(vii) The phase change must have a high latent heat effect that is it must store large large quantities of heat.

(viii) The material must be available in large quantities.

(ix) The preparation of the phase changing material for use must be relatively simple.

(x) The material must be harmless (non-toxic non-inflammable non-combustible, non-corrosive).

(xi) A small volume change during the phase change.

(xii) The material should have high thermal conductivity in both the phases. If these criteria can be met, phase change energy storage system can be of high capacities (relative to energy storage in sensible heat systems) when operated over small temperature ranges, with substantial reduction in volume and weight.

Materials for Phase Change Energy Storage.

There are several materials that undergo a change of phase. Glauber's e ($Na_2SO_4.10H_2O$) water, $Fe(N03)_2$ 6H $_2$O, and salt Eutectics are due used.

Glauber's ($Na_2S0_4 . 10 H_20$) (sodium sulphate decahydrate) phase changes from solid to liquid requires less energy than those liquid to gas, but some solid to liquid changes, still provide amount of storage potential. Phase change materials involving water of dehydration have long been experimented with solar energy, one of these is Glauber's salt, which decomposes at about 32°C to given solution plus Na2S04 with a heat of fusion of 243 kJ per kg (56kcal/kg) and has been proposed mainly for storing domestic heat. The reaction is

$$Na_2S0_4 . 10 H_20 + \text{energy} = Na_2S0_4 + 10 H_20$$

Energy storage is accomplished by the reaction proceeding from left to right on addition of heat. Energy extraction from storage is the reverse procedure, with the reaction proceeding from right to left and thermal effects reversed. It has been found that the performance decades on repeated cycling, with the thermal capacity of the system reduced $Na_2S0_4 . 10 H_20$ has an incongruent melting point, and has its temperature increases beyond the melting point, it separates into liquid (solution)phase and solid Na_2S04' Since density of salt is higher than the Density of the solution, a phase separation occurs. Attempts have been made to use gels or other agents to avoid phase separation. The above Difficulties have been overcome by keeping the material in long thin containers and by mixing certain additives as mentioned.

A latent heat storage arrangement is shown in Fig. 2.53(a), in which, the storage material is placed in long thin containers, e.g., cylinders, and the gas is passed through narrow spaces between the

Fig 2.53(a) Typical latent heat storage arrangements

An advantage associated with this storage system is that it is more compact than a sensible heat system.

Some organic compound or substances serve as heat storage materials due to the desirable properties that possess in comparison inorganic compounds. Some of these advantages include their ability to melt congruently, their self-nucleating properties, their capability to freeze without super cooling and their compatibility with conventional materials of construction. Paraffin and fatty acids, are the two candidates organic substances qualified as heat of fusion materials. Paraffins possess generally high heats of fusion and are available large temperature ranges. They are known to freeze without super cooling. fatty acids are known to possess a reproducible melting and freezing behavior and freeze with little or no super cooling. Hence these qualify a good phase change thermal energy storage materials with a major drawback of higher cost.

Refractory materials (MgO, Al_2O_3, SiO_2) are also suitable for high temperature sensible heat storage in addition to Rock or pebble bed storage. Some thermal storage materials such as $ZnCI_2$, $Na(OH)_3$, NaOH,KOH-$ZnCI_2$ KCI-$MgCl_2$—NaCI, $MgCl_2$ NaCI, etc. are also used for the temperature range of 200-450°C.

c) Thermal stratification is possible as water becomes less dense when heated; **meaning** water weighs less per unit volume. Therefore, warmer water will be lighter and colder water will be heavier. Due to this, there will always be a level of "self-induced" **thermal stratification** in a water **storage**

Improvement in storage is actually achieved by thermal stratification; that is, water of a high temperature than the overall mixing temperature can be extracted at the top of the container and water of a lower temperature than the mixing temperature can be drawn off from the bottom to make use even of short insolation periods and thus running the collector at a higher efficiency. In practice, perfect stratification is not possible since the water entering the tank will cause a certain amount of agitation and mixing. Moreover, there would be a certain amount of diffusion from the entering water (to the stored water) before it reaches the appropriate density level. Having obtained good thermal stratification by eliminating mixing, it is equally important to maintain the temperature layers. Due to the heat losses from the surface of the storage tank, the temperature of water near the vertical walls is lower, leading to natural convection currents that destroy the temperature layers. In order to maintain stratification over long time intervals, the tank should be provided with extremely good thermal insulation or with special installations.

An idea in assisting thermal stratification is, for example, the use of a thin plastic tube of the same density as the water as illustrated. The tube moves up and down according to the density of the hot water, placing the warm water in the right part of the tank

In the case of thermal stratification in storage, an improvement in both storage and collector performance is achieved. There are three advantages

1. In a thermally stratified hot liquid tank, liquid at a higher temperature than the overall mixed mean temperature can be extracted at the top of the tank, thereby improving the satisfaction of the load.

2. The collection efficiency from the collector is improved since the collector inlet fluid temperature is lower than mixed mean storage temperature.

3. The stratified storage can be at a lower mixed mean temperature for any given temperature requirement from the load, thereby reducing heat losses from the storage tank.

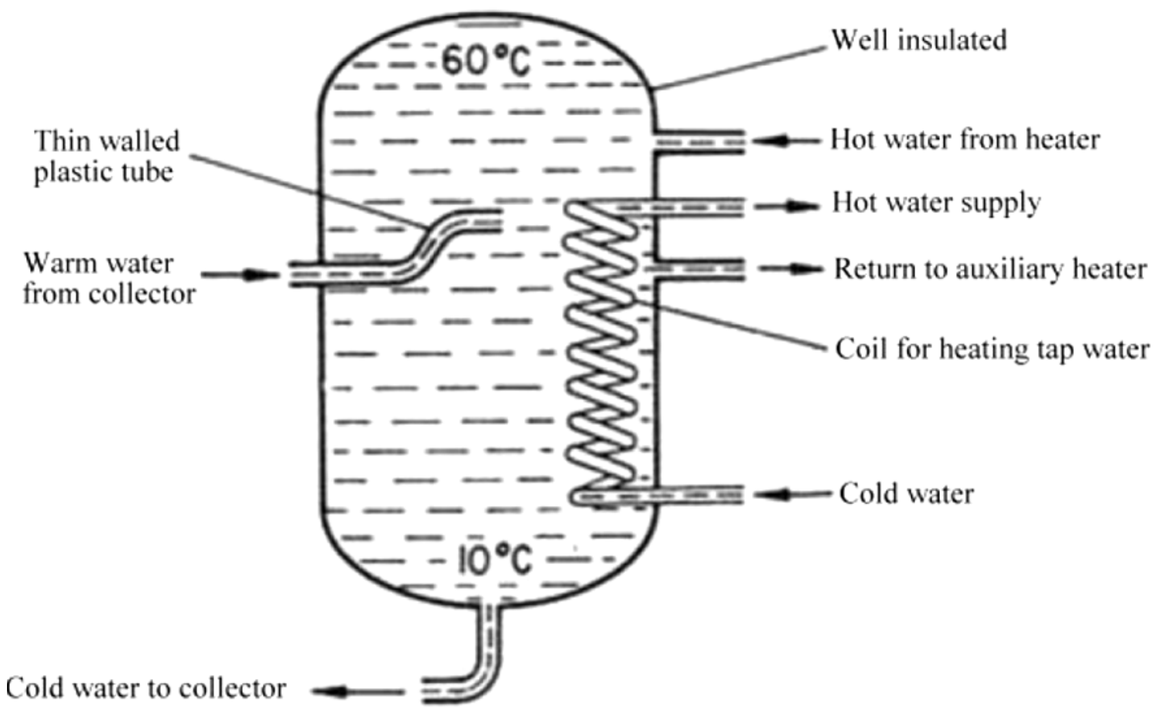


Fig 2.54 thermally stratified hot liquid tank

The absolute and relative importance of either of these effects will, of course, depend on the solar system design and the intended application.

The thermal stratification described so far is that produced due to buoyancy forces, which ensure highest temperature at the top and lowest temperature at the bottom of the tank (also known as temperature-ordered stratification). A monotonically increasing temperature from bottom to top is possible in such stratification. However, since complete stratification is never achieved in a real system, an alternative type of stratification employing multiple storage tanks at different temperatures is also meaningful. Such stratification is in fact enforced stratification: the liquid in different tanks remains at different temperatures even when the liquid in each tank is completely mixed, due to the physical separation between tanks. Forced stratification occurs also in rock beds, since hot air is brought in contact with different parts of the rock bed in the path of its flow and these parts of the rock bed, heated to different temperatures, cannot mix.

There are six temperature distribution models to idealize the real temperature distribution in the system. They are Linear, Stepped, Continuous Linear, General Linear, Basic Three Zone and General Three Zone. Each of above models can be used to idealize the system. But there is one model, which gives more accurate results. This is the Stepped Temperature Distribution Model.

In the governing equations the stepped-temperature model is used. This model consists of *k* horizontal zones, each of which is at a constant temperature, and can be expressed as

$$T(h)\begin{cases} T1, ho \leq h \leq h1 \\ T2, h1 < h \leq h2 \\ - \\ Tk, hk-1 < h < hk \end{cases}$$

where the heights are constrained as follows:

$0 = h_0 \leq h_1 \leq h_2 \leq \ldots \leq h_k = H$

It is convenient to introduce here x_j, the mass fraction for zone j:

$x_j = \frac{mj}{m}$

since the TES fluid density ρ and the horizontal TES cross-sectional area *A* are assumed constant here, but the vertical thickness of zone *j*, $h_j - h_{j-1}$, can vary from zone to zone,

$m_j = \rho V_j = \rho A(h_j - h_{j-1})$,

and the total mass is

$m = \rho V = \rho AH$

Where V_j and V denote the volumes of zone j and of the entire TES, respectively. If the last two equations are substituted into the mass fraction formula we get:

$$x_j = \frac{h_j - h_{j-1}}{H}$$

It can be shown that:

$$T_m = \sum_{j=1}^{k} x_j T_j \; .$$

T_m is the fully mixed temperature of the storage or the weighted mean of the zone temperatures, where the weighting factor is the mass fraction of the zone. On the other hand:

$$Te = exp\left(\sum_{j=1}^{k} xj \ln Tj\right) = \prod_{j=1}^{k} Tj^{\,xj}$$

where T_e represents the equivalent temperature of a mixed TES that has the same energy as the stratified TES. In general, $T_e \neq T_m$, since T_e is dependent on the degree of stratification present in the TES, while T_m is independent of degree of stratification. In fact $T_e = T_m$ is the limit condition reached when the TES is fully mixed.

In the operation of the TES there will be energy losses and minimization of the energy losses is desired.

2. Electrical Storage.

Theoretically Capacitors could store large amounts of electrical energy for long periods. The total energy stored is

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

where V is the volume of the dielectric

ε is constant and

E is the electric field strength.

Electric field strength is limited by the breakdown strength E_{br} of the dielectric. Therefore, the electrical energy storable in a dielectric is limited. At present best dielectric material available is mica

Practically, because the conductivity of a dielectric is never nil, there will always be leakage losses. At present, capacitive storage is economical for times no longer than 12 hours. To increase this time much research is needed. Therefore, unless better and cheaper dielectric materials for storing electric energy. are found, capacitative storage on a large scale will remain uneconomical.

Whereas capacitors store electrical energy at high voltage and, low current, inductor storage is at low voltage and high Current. Thus energy stored in an inductor is .

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

Where µ. is the permeability of the material and

H_m is the magnetic flux density.

For H_{ind} to be large, both µ. and H_m should be large. Consequently, high magnetic fields are required. This will create large mechanical forces which should be supported by strong structures. The reverse operation of discharging the stored energy creates another problem since it involves the opening of circuit carrying large currents.

Battery Storage.

A battery is a combination of individual cells A cell is the elemental combination of materials and electrolyte constituting the basic electrochemical energy storer. A battery can also be thought of as a black-box into which electrical energy is put stored electrochemically, and later regained as electrical energy. Battery storage system may be included under chemical energy storage also Secondary batteries are of chief interest for solar electrics, which are rechargeable, whereas primary batteries are non rechargeable Examples of secondary batteries are lead acid, nickel cadmium, iron air, Nickel-hydrogen, zinc-air, sodium sulphur, sodium-chlorine etc

A generalized cell consisting of two electrodes called the anode and cathode immersed in a suitable electrolyte. When an electrical load is connected between the electrode charge separation occurs at the interface between on electrode and the electrolyte, freezing both an electro n and an iron. The electron flows through the external load and ion through the electrolyte, recombining at the other electrode.

Energy efficiency of a battery is defined as (sometimes called watt hour efficiency)

$$\eta_{energy} = \frac{\int_0^{t_1} I_1 E_1 \, dt}{\int_0^{t_2} I_2 E_2 \, dt} \qquad \text{.........(1)}$$

I_1 = Battery discharge current

E_1 = Battery discharge terminal voltage

I2 = Battery charging current

E_2 = Battery charging terminal voltage

t_1 = Battery discharging time

t_2 = Battery charging time.

Two special cases of equation (1) are of interest to the system engineers. If the discharge and charge occurs at constant voltages then equations reduces to :

$$\text{Energy efficiency} = \frac{E_1 \int_0^{t_1} I_1\, dt}{E_1 \int_0^{t_2} I_2\, dt}$$

$$= \frac{E_1 \times \text{Amp. hour output}}{E_2 \times \text{Amp. hour input}} \qquad \text{.......(2)}$$

The integrals might be evaluated graphically. Once found multiplication by the respective terminal voltage gives the watt hours of the input or output. Equation (2) suggests why for some types batteries with nearly constant terminal voltage the chief interest might be in the

I vs t curve for discharge or charge. The ampere hour output of a battery is A very common way of rating. If the discharge and charge occurs at constant currents; then equation(1) becomes

$$\text{Energy Efficiency} = \frac{I_1 \int_0^{t_1} E_1\, dt}{I_2 \int_0^{t_2} E_2\, dt}$$

If neither current nor voltage is held constant, then we must resort to equation (1) directly and either graphically or electronically evaluate the integrals to determine the energy efficiency for the battery Cycle life is the number of times the battery can be charged and discharged under specified conditions. The cycle life of a battery may vary greatly with the depth of the discharge, deep discharge tending to result in short cycle life. However, deep discharge may be difficult to avoid in some battery applications as an electric vehicles.

Fundamentals of solar photo voltaic conversion – Solar cells – Solar PV Systems – Solar PV applications

25. Explain the process of Solar Electric Power Generation: Solar Photo-Voltaic.

Introduction: The direct conversion of solar energy into electrical energy means of the photo voltaic effect, that is the conversion of light(or other electromagnetic radiation) into electricity. The photo voltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation. Energy conversion devices which are used to convert sunlight to electricity by the use of photo voltaic effect are called solar cells. A single converter cell is called a solar cell or, more generally, a photovoltaic cell, and combination of such 'cells; designed to increase the electric power output is called a solar module or solar array.

Photovoltaic cells are made of semiconductors that generate electricity when they absorb light. As photons are received, free electrical charges are generated that can be collected on contacts applied to the surfaces of the semiconductors. Because solar cells are not heat engines and therefore do not need to operate at high temperatures, they are adopted to the weak energy flux of solar radiation, operating at room temperature. These devices have theoretical efficiencies of the order of 25 per cent. Actual operating efficiencies are less than half this value, and decrease fairly rapidly with increasing temperature.

The best known application of photovoltaic s for electrical power generation has been in space craft which the silicon solar cell is the most highly developed type. The Silicon cell consists of a single crystal of silicon into which a doping material is diffused to form a semiconductor. Since the early days of solar eel development, many improvements have been made in crystal growing and doping, electrical contact and cell assembly and production methods. Large number of cells has been manufactured with area 2x 2 cm, efficiencies approaching 10 percent, and operating at 28°C. The efficiency is the power developed per unit area of array divided by the solar energy flux in the free space (1.353 kW/m^2).

For terrestrial applications, silicon solar cells have shown operating e efficiencies of about 12 to 15 per cent. Though silicon is one of the earth's most abundant materials, it is expensive to extract (from sand where it occurs mostly in the form $Si0_2$) and refine to the purity required for solar cells. The greater barrier to solar cell applications lies in the in the costs of the cells themselves. Reducing the cost of silicon cells is difficult because of the cost of making single crystal. One very promising method is being developed to produce continuous thin ribbons of single crystal silicon to reduce fabrication costs. Cells made from the ribbon have so far shown efficiencies of around 8 per cent. Several other kinds of photocells are in the laboratory stage of development. Cadmium sulfide and CdS/Cu_2S cells are other possibilities. So far, efficiencies have been in the range of 3 to 8 per cent, and these cells have been less durable than silicon cells owing to degradation with exposure to oxygen. water vapour and sunlight, especially at elevated temperatures'. The active part of the CdS cell is a thin polycrystalline layer of CdS, about 10 μm thick, on which a layer ofCu_2S compound perhaps O.1 μm thick is grown. These cells can be made by deposition on long sheets of substrates, a process that might be adaptable to expensive mass production.

Photovoltaic cells could be applicable. to either small or large power Plants, since they function well on a small scale, and may be adaptable to local energy generation on building roof tops. The cost of energy storage and power conditioning equipment might, however make generation in large stations the most economical method. Solar cells have also been used to operate irrigation pumps, navigational signals, highway emergency call systems rail road crossing warnings, automatic meterological stations, etc., in locations where access to utility power lines is difficult.

26. Explain the components involved in solar PV (photo-voltaic) in details. (N/D'13) (or) Explain the principle of solar photovoltaic energy conversion system. (Nov/Dec 2020)

Solar PV (photo-voltaic) consists of

(i) Solar cell array

(ii) Load leveler

(iii) Storage system

(iv) Tracking system (where necessary).

In actual usage, the solar cells are interconnected certain series/parallel combinations to form modules. These modules are hermetically scaled for protection against corrosion, moisture, pollution and weathering. A combination of suitable modules constitutes an array. One square meters of fixed array kept facing south yields nearly 0.5kWH of electrical energy on a normal sunny day if the orientation of the array is adjusted to face the sun's ray at any time, the output can increase by 30 percent. Solar PV system can produce an output only if sunlight is present. If it is required to be used during non sunshine hours, suitable systems of storage batteries will be required.

Solar Cell Principles

The photovoltaic effect can be observed in nature in a variety of materials, but the materials that have shown the best performance in sunlight are the semiconductors as stated above. When photons from the sun are observed in a semiconductor, they create free electrons to flow out of the semiconductor to do useful work. The electric field in most solar cells is provided by junctions of materials which have different electrical properties

To obtain a useful power output from photon integration in a semi-conductor three processes are required.

1. The photons have to be observed in the active part of the materials and result in the electron being excited to a higher energy potential.
2. The electron-hole charge harrier created by absorption must be physically separated and moved to the edge of the cell.
3. The charge carriers must be removed from the cell and delivered to a useful loose their extra potential.

For completing the above process, a solar cell consists of:

a) Semi conductor in which electron hole pairs are created by absorption of incident solar radiation.
b) Region containing a drift field for charge separation, and
c) Charge collecting front and back electrodes.

The photo voltaic effect can be described easily for p-n junction in a semi conductor. In an intrinsic semi conductor such as silicon, each one of the four valence electrons of the material atom is tied in a chemical bond, and there are no free electrons at absolute zero. If a piece of such a material is doped on one side by a five valence electron material, such as arsenic or phosphorous, there will be an excess electrons in that side, becomes an n-type semiconductor. The excess electrons will be practically free to move in the semi conductor lattice. When the other side of the same piece is dropped by a three valence electron materials, such as boron there will be deficiency of electrons leading to a p-*type* semiconductor This deficiency is expressed in terms of excess 0 0 es ree move in the lattice.(such a piece of semi-conductor with one side of the *p-type* and the other of the n-type is called-a p-n junction. *In this* Junction after the photons are absorbed, the free electrons of the n-side will tend to flow to the p-side, and the holes of the p-side will tend to flow to the *n* region to compensate for their respective deficiencies.

This diffusion will create an electric field *EF* from the n region to the p region. This field will increase until it reaches equilibrium for *Ve.* the sum of the diffusion potentials for holes and electrons. If electrical contacts are made with the two semiconductor materials and the contacts are connected through an external electrical conductor, the free electrons will flow from the n-type material through the conductor to the *p-type* material (Fig. 5.). Here the free electrons will enter the holes and become bound electrons ; thus, both free electrons and holes will be removed. The flow of electrons through the external conductor constitutes an electric current which will continue as long as more free electrons and holes are being formed by the solar radiation. This is the basis of photovoltaic conversion that is, the conversion of solar energy into electrical energy. The combination of n type and p type semiconductors thus constitutes a photovoltaic (PV) cell or solar cell. All such cells generate direct current which can be converted into alternating current if desired.

The most normal configuration for a solar cell to make a p-n junction semiconductor is shown in fig 3.27. Shows the junction of the 'p-type' and 'n-type' materials provides an inherent electric field separates the charge created by absorption of sunlight. This p-n junction is usually obtained by putting a p-type dopant

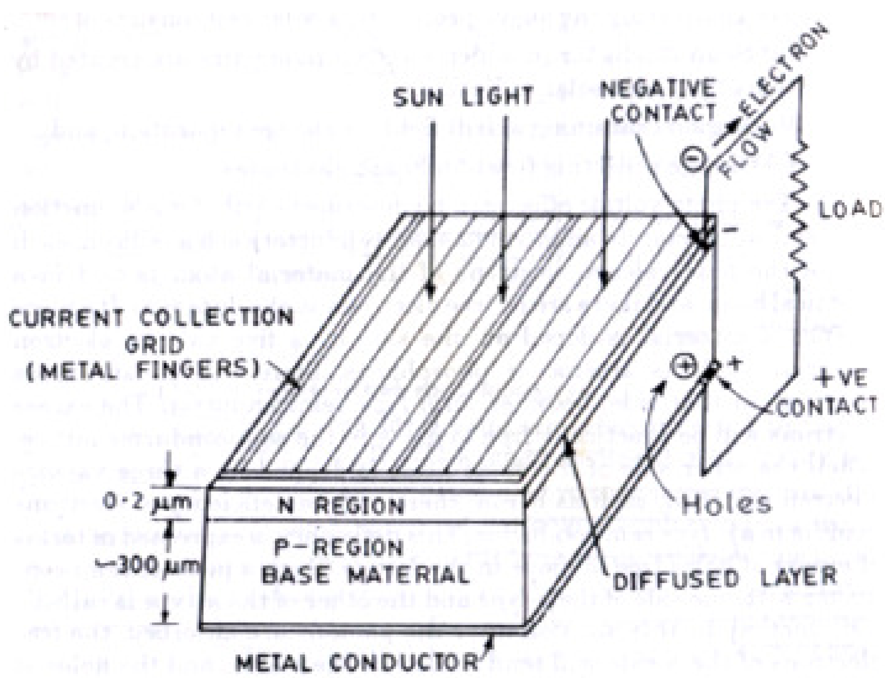


Fig 2.55 Schematic view of a typical solar cell

Such as phosphorus and allowing the n-dopant to diffuse into the surface about 0.2 μm. The junction is thus formed slightly below the planar surface of the cell and the light impinges perpendicular to the junction. The positive and negative charges created by the absorption of photons are thus encouraged to drift to the front and back of the solar cell. The back is completely covered by a metallic by metallic contact to remove the charges t the electric load. The collection of charges from the front of the cell is aided by a fine grid of narrow metallic fingers.

The surface coverage of the conducting collectors is typically about 5 percent in order to allow as much light as possible to reach active junction area. An antireflective coating is applied on the top of the cell. Fig 2.56 demonstrates how this p-n junction provides an electric field that sweeps the electrons in one direction and the positive holes in the other. If the junction is in thermodynamic equilibrium, then the Fermi energy, must be uniform throughout. Since the Fermi level is near the top of the gap of an n-doped material and near the bottom of the p-doped side, an electric field must exist at the junction providing the charge separation function of the cell. Important characteristics of the Fermi level is that, in thermodynamic equilibrium, it is always continuous across two materials the contact between the two materials.

Each of the individual solar cells will produce power at about 0.5V with the current directly proportional to the cell's area. The individual cells are connected in series-parallel combination to meet the voltage, power and reliability requirements of the particular application. Space cells are covered with transparent 'cover slips' to absorb the high energy particles in space that could cause damage in the cell and result in a degradation of output. For terrestrial applications, the solar cell panels have to be encapsulated to protect them from atmospheric degradation due to oxidation of the metal contacts, which would cause peeling and open circuits materials such as glass, acrylics or silicon epoxies are used to provide a clear, weather fight front covering for the panels

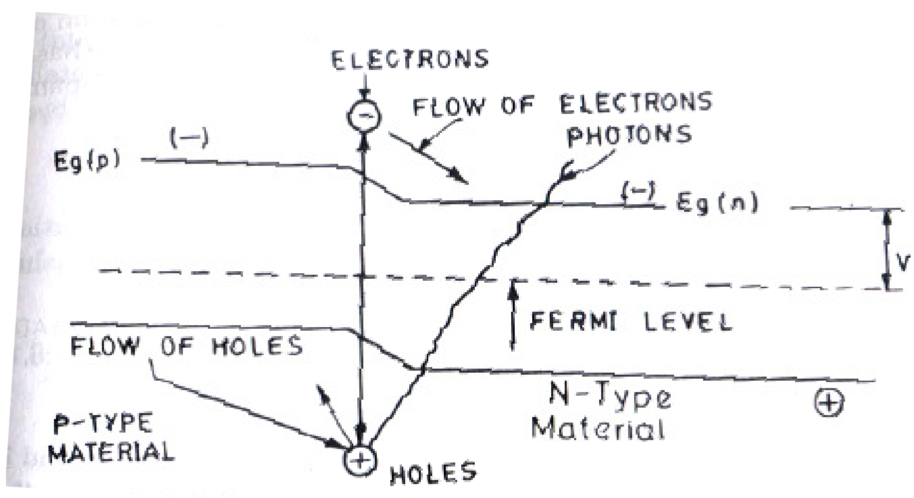


Fig 2.56 P-n junction electric fields

Semiconductor Junctions.

Modern solar cells make use of semiconductor materials, usually based on single-crystal silicon. When doped with phosphorus, arsenic, or antimony, the silicon becomes an n-type semiconductor as stated earlier; and when doped with boron, aluminium, indium, or gallium, it forms a p-type semiconductor (fig 3.28). If a p-type semiconductor is brought into intimate contact with one of the n-type, they form a p-n (or n-p) junction. If the two semiconductor materials are derived from the same element (or compound) such as silicon the system is referred to as homo-junction' is also possible for a p-n (or n-p) junction to be formed from two different semiconductor materials, such as cadmium s e (CdS) and cuprous sulfide (CU2S) ; this is known as a hetero-junction The general behavior at the junction, as outlined above, same is e s regardless of the type. The Schottky junction consisting of a semiconductor and metal. This junction is formed by depositing a thin layer of a metallic conductor (e.g. platinum) onto a p- or n-type semiconductor. Shottky junction photovoltaic cells made with the so-called amorphous silicon are more efficient than homoJunction p-n cells of the same material. Cost of it, is also less.

The MIS (metal insulator-semiconductor) solar cell is similar to the Schottky type except that a very thin layer (about 0.1 to 0.3 um) of an insulator is deposited between the semiconductors or and the metallic conductor. A conversion efficiency of more than 17 percent has been reported for an MIS solar cell made with single crystal silicon.

Conversion Efficiency and Power Output

A solar cell usually uses a *p-n* junction its physical configuration is shown schematically in Fig. 5.6.1. Current 'and voltage relationship is given by

$$j_i = j_o\left[\exp\left(\frac{Ve}{KT}\right) - 1\right]$$ ---------Eq 1

where

j_o, is the saturation current also called the dark current and is obtained when a large negative voltage is applied across the diode.

V is the voltage across junction

e is the electronic charge

k is Boltzmann's constant

T is the absolute temperature

When light impinges on the junction, electron hole pairs are created at a constant rate providing an electrical current flow across the junction. The net current is thus the difference between the normal diode current and light generated current j_L, Simplified equivalent circuit for the cell is shown in Fig. 2.57. The internal series resistance *R;* is mostly due to the high sheet resistance of the diffused layer which is in series with

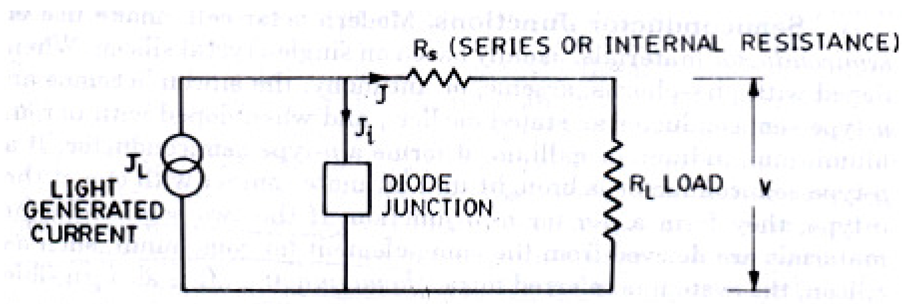


Fig 2.57. The equivalent circuit of a solar cell

the junction. The light generated current acts as a constant current source supplying the current to either the junction or a useful load depending on the junction characteristic and the value of the external load resistance. The net *current J* is given by

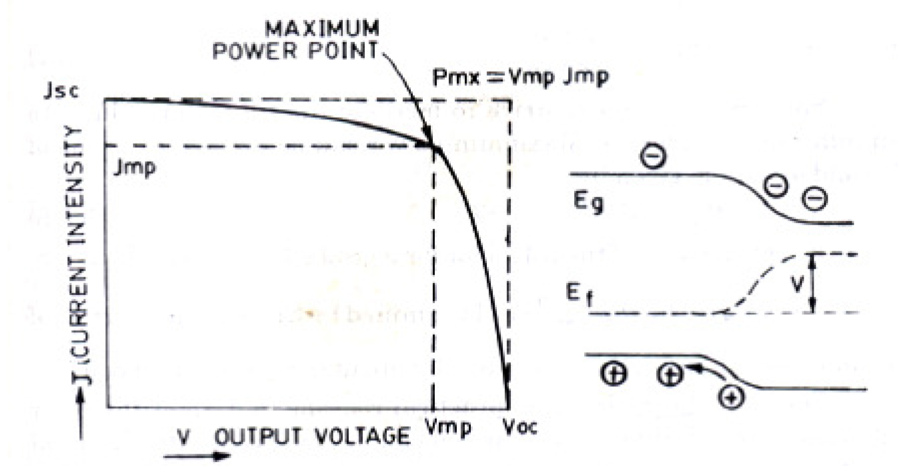
$$J = J_L - J_i = J_L - J_0\left[\text{Exp}\left(\frac{Ve}{kT}\right) - 1\right]$$

--------------Eq 2

The internal voltage drop in a cell can usually be minimized, and for ideal cell R_S may be assumed equal to zero i.e. R_S = O. With these the corresponding J - *V* plot is given in Fig. 2.58 (a). Open circuit voltage *Voc* for the ideal cell is then given by

$$V_{OC} = \left(\frac{kT}{e}\right)\ln\left[\frac{J_L}{J_0} + 1\right]$$

---------------Eq 3



(*a*) Current Voltage Curve (*b*) Electron Energy Diagram

Fig 2.58 (a) A typical J –V plot for an ideal solar cell

JL>>Jo, the 1in the equation can be neglected. Then open circuit voltage

$$V_{0C} = \frac{kT}{e} \ln \frac{J_L}{J_0}$$ -------eq 4

In practice the open circuit voltage of the cell decreases with increasing temperature.

The maximum power that can be derived from the device is given by

$P_{max}=V_{mp}.J_{mp}$--------EQ 5

where V_{mp} and J_{mp} are the voltage and current at maximum power point as shown in Fig. 2.58 respectively. It can be seen that the maximum efficiency for the cell is obtained by dividing V_{mp} *and* J_{mp} by the total power density of the sunlight P sun.

$$\text{Thus} \qquad \eta = \frac{V_{mp} J_{mp}}{P_{sun}}$$

$$= \left(\frac{J_L E_g}{e P_{sun}}\right) \underbrace{\left(\frac{J_{mp} V_{mp}}{J_L V_{0C}}\right)}_{\text{Fill factor}} \underbrace{\left(\frac{e V_{0C}}{E_g}\right)}_{\text{Voltage Factor}}$$ -------EQ 6

[where *Eg* = Forbidden energy gap]

The fill factor *(FF)* for a solar cell is defined as the ratio of two areas shown.

$$\text{or} \qquad FF = \frac{J_{mp} V_{mp}}{J_L \times V_{0C}}$$ --------EQ 7

Solar cell designers, strive to increase the fill factor values, to minimize internal losses. Maximum-power can be defined in terms of V_{oc} and J_L and is given by

$P_{max}=J_L \times V_{oc} \times FF$

A typical value of the fill factor for a good silicon cell is about 0.8. The voltage factor is $\frac{e\,Voc}{Eg}$determined by the basic properties of the materials in the cell and is typically about 0.5 for a silicon cell. For both theoretical J and ~al reasons, not all of the solar radiation energy falling on a solar cell can be converted into e electrical energy. A specific amount of energy is required to produce a free electron and hole in the semi-conductor material. In silicon for example, the energy minimum is 1.1 electron volts and this is available in radiation having a wavelength of 1.1 micrometers (um or less). Consequently infrared radiation of longer wavelength has no photovoltaic effect in silicon but is largely absorbed as heat. Furthermore, even the energy of radiation with shorter wavelengths cannot be used completely; energy in excess of that needed to free a bound electron is simply converted into heat.

For the foregoing reasons, only about 45 percent of the energy in the solar radiation at sea level is capable of producing electrons and holes in silicon. However, because of the electrical resistance of the semi- conductor material and other loss modes, the maximum practical efficiency for the conversion of solar energy into electrical energy in a silicon solar cell is estimated to be about 21 per cent. P voltaic semi-conductors with conversion efficiencies upto about 25 per cent or more are known *(e.g.* gallium arsenide), but it is uncertain if the extra conversion efficiency can compensate for the additional cost, except in special circumstances.

Because of internal losses arising from minute amounts of impurities, from defects in the silicon crystal, and from recombination of electrons and holes before they can be separated, and external losses from reflection, most commercial silicon solar cells have a conversion efficiency of roughly 13 to 14 per cent (average about 12 per cent). However cells have been made with efficiencies of 18 per cent, and this level will probably be attained in commercial cells.

The power output (in watts) of any generator of electricity, including a photovoltaic cell, is equal to the product of the voltage and current)Theoretically, a silicon solar cell should have a voltage of 1.1 volts, from 1.1 electron-volts energy of the free electrons produced. In practice, however, the maximum voltage is about 0.6 volt and this occurs on open circuit, when no power is produced. The maximum power of a silicon cell occurs at an output voltage of approximately 0.45 volt. In full sunlight, the current from a commercial cell is then roughly 270 amperes per sq. m of exposed surface. The power is thus about 0.45 x 270 = 120 watts (or 0.12 kW) per sq. m *(i.e.* 13 watts/sq. ft.).

The rate at which solar energy reaches the top of the atmosphere *(i.e.* the solar constant) is 1.353 kilowatts/sq. m (1.353 kW/sq. m). Part of this energy is reflected back to the space, and part is absorbed by the atmosphere. In full sunlight, the solar energy may reach the ground at a rate of roughly 1 kW/sq.m.

The electric power output of photovoltaic cell is roughly proportional to the rate at which solar radiation falls on its surface. Hence e output of a cell of a given area can be increased by combing it with a concentrating collector. Tracking collectors of the line-focus type can provide a concentration of a few hundred fold. With the compound parabolic (non focusing) concentrator (CPC), a concentration factor of about ten is possible without tracking. Since focusing collectors concentrate direct solar radiation only (but not diffuse radiation), they would be most useful in regions of high insolation. However, this limitation might not be applicable to the CPC, since it can collect diffuse (scattered) radiation.

Most of the solar energy that is not converted into electricity in a photovoltaic cell is absorbed as heat. In a commercial, single-crystal silicon cell, for example, with a conversion efficiency of about 12 per cent, more than 80 per cent of the incident solar energy appears as heat in the cell. As the temperature increases, the efficiency of an *n-p* homo junction silicon cell will decrease, for example, for a commercial cell it is about 8 per cent at 100°C. Cells made of gallium arsenide are superior to silicon cells for operation at elevated temperatures; their higher cost may then be justified when used with concentrating collectors. The conversion efficiency of a practical gallium arsenide solar cell is roughly 18 per cent at ordinary temperatures, 16 per cent at 100^0Cand 12 per cent at 200°C. Gallium arsenide is a good absorber of solar

25. Explain the working of grid connected solar power plant. (Nov/Dec 2020)

A Basic Photovoltaic System for Power Generation

A basic photovoltaic system integrated with utility grid is shown in fig 2.59. it permits solarly generated electric power to be delivered to a local load. It consists of:

i) Solar array, large or small, which converts the isolation to useful DC electric power

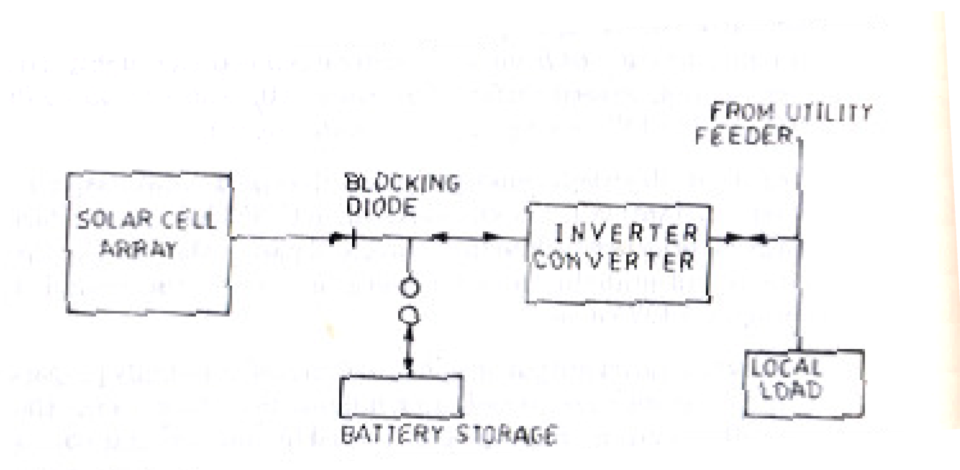


Fig 2.59 Basic photovoltaic system integrated with power grid

ii) A blocking diode

Which lets the array- generated power flow only toward the battery or grid. without a blocking diode the battery would discharge back through the solar array during times of no insolation

iii) Battery storage in which the solarly generated electrical energy may be stored

(iv) Inverter/converter, usually solid scate which converts the battery bus voltage to AC of frequency and phase to match that needed to integrate with the utility grid. Thus it is typically a DC, AC inverter. It may also contain a suitable output step up transformer, perhaps some filtering and power factor Connection circuits and perhaps some power conditioning, *i.e.* circuitry to initiate battery charging and to prevent over charging. Power conditioning may be shown as a separate system functional block. This block may also be used in figure shown to function as a rectifier to charge the battery from the utility feeder when needed and when no insolation was present.

(V) Appropriate Switches and Circuit Breakers, to permit isolating parts of the system, as the battery. One would also want to include breakers and fusing protection (not shown) between the inverter output and the utility grid to protect both the photovoltaic system and the grid.

Solar Cell Modules (Solar Photovoltaic Arrays)

There may be tracking arrays or modules or fixed arrays. A tracking array is defined as one which is always kept mechanically perpendicular to the sun-array line so that all times it intercepts the maximum insolation; such arrays must be physically movable by a suitable prime mover and are generally considerably more complex than fixed arrays. A fixed array is usually oriented east west and tilted up at an angle approximately equal to the latitude of the site(fixed arrays are mechanically simpler than tracking arrays. Thus the array design falls into two broad classes.

(1) Flat-plate Arrays.

Wherein solar cells are attached with a suitable adhesive to some kind of substrate structure usually semi rigid to Prevent cells being cracked.

This technology springs from the space-related photovoltaic technology, and many such arrays have been built in various power Sizes.

(2) Concentrating Array

Wherein suitable optics, *e.g.* Fresnel lenses, parabolic mirrors, compound parabolic concentrators (CPC), and others, are combined with photovoltaic cells in an array fashion. This Technology new to photovoltaics in terms of hardware development, and comparatively fewer such arrays have actually been built.

Solar cell connecting arrangements.

Cells may be connected in parallel to achieve the desired current and then stacked in series to achieve the desired voltage. The optimum operating voltage of a photovoltaic cell is generally about 0.45 volt at normal temperatures, and the current in full sunlight may be taken to be 270 amperes/sq. m. If the exposed area of a cell is 40 sq. cm or 40 x 10-4 sq. m. the current would be 1.08 amperes and the electric power output 0.45 x 1.08 = 0.49 watts, in full sunlight. A decrease (or increase) in the solar radiation has little effect on the voltage, but the current an power are decreased or increased) proportionately.

By combining a number of solar cells in series *(i.e.* in a string) the voltage is increased but the current is unchanged. For example, 110 volts, for operating commercial tools, motors, or domestic appliances, would require $\frac{110}{0.45}$ = 244 cells in series. To increase the current output at the same time, several strings of 244 cells would be connected in parallel, as depicted in Fig. (2.60).

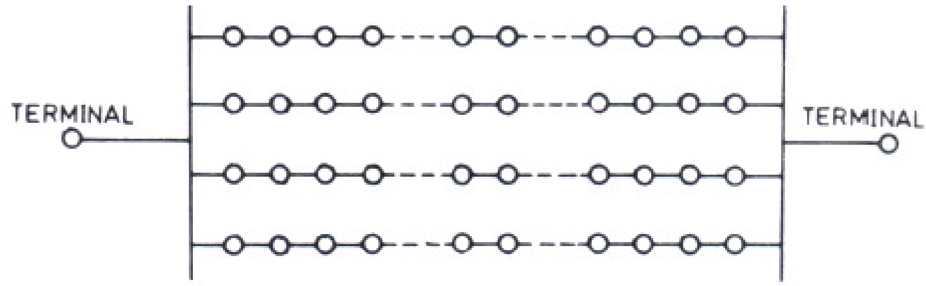


Fig 2.60 Solar cell arrangements in series and parallel

Suppose there were ten such strings in parallel, the current under optimum conditions would then be 10 x 1.08 = 10.8 amperes, and the power output would be 10.8 x 110 = 1190 watts or 1.19 kW. The so called solar panels on space craft consist of modules (or arrays) of cells connected in series and parallel to produce the required voltage and power.

If even a single cell in a string should fail, the whole string would become inoperative. The cells in the remaining strings would maintain the voltage, but the current (and power) output of the system would be decreased by the loss of one string of cells. A short circuit in a cell would not disable the string, although there would be a slight drop in voltage. There is a possibility that the other cells might cause current to flow in the wrong direction through any string having a reduced voltage. This danger is eliminated by including a diode, which permits current flow in one direction only, at end of each string. Instead of a number of strings of cells in parallel, the current (and power) could 'be increased by locating a single string of cells at the focal line of a sun tracking, parabolic trough, and concentrating collector. There would be some decrease in voltage because of the inevitable higher temperature of the solar cell material, but the current would increase approximately in proportion to the concentration factor of the collector. Thus, with a concentration factor of 100, the current from a single string would be increased to about 100 amperes. If the number of cells in the string is sufficient to produce 110 volts, the total electric power output would be approximately 12kW.

Battery Storage.

The simplest means of storage on a smaller moderate scale is in electric *storage batteries,* especially as solar cells produce the direct electric current required for battery charging. The stored energy can then be delivered as electricity upon discharge. The common lead acid storage batteries, such as are used in automobiles, are not ideal for this purpose, but they are probably the best presently available. Extensive research in progress should lead to the development of more suitable batteries.

A possible alternative is to use the direct current from solar cells to decompose water (by electrolysis) into hydrogen and oxygen gases. These gases would be stored in a suitable form and utilized as needed to generate electricity in a *fuel cell.*

Inverters.

These are the devices usually solid state, which change the array DC output to AC of suitable voltage, frequency, and phase to feed photovoltaically generated power into the power grid or local load, as shown in figure. These functional blocks are sometimes referred to as power conditioning.

A general type of inverter circuit which is found best suitable for the utility application is shown in Fig. (2.61). The current can be used in two modes: (1) as an inverter changing DC to AC or (2) as a rectifier changing AC to DC, thus charging the battery.

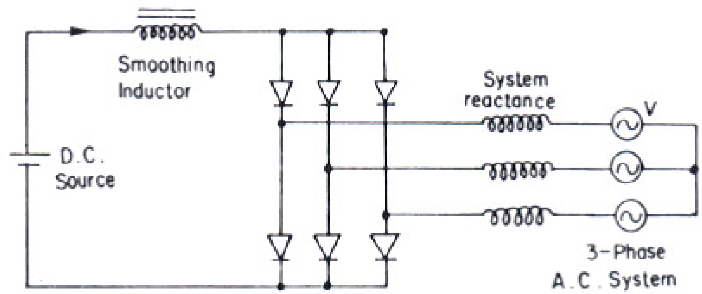


Fig 2.61 Current –fed line commutated inverters.

It is clear that the system photovoltaic offers the options of DC power, AC power, hydrogen and oxygen fuels in either gas or liquid forms from which electricity can be generated. The system has many advantages and disadvantages.

Applications of Solar Photovoltaic System

Various solar photovoltaic systems have been developed and installed at different sites for demonstration and field trial purposes. The *terrestrial* applications of these include provision of power supply to:

(i) Water pumping sets for micro irrigation and drinking water supply,

(ii) Radio beacons for ship navigation at ports,

(iii) Community radio and television sets,

(iv) Cathodic protection of oil pipe lines,

(u) Weather monitoring,

(vi) Railway signaling equipment,

(vii) Battery charging,

(viii) Street lighting.

The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural areas. The photovoltaic water pumping system essentially consists of:

(a) a photovoltaic (PV) array,

(b) Storage battery,

(c) Power control equipment,

(d) Motor pump sets, and

(e) Water storage tank.

Advantages and Disadvantages of Photovoltaic Solar Energy Conversion

Advantages:

(i) Direct room temperature conversion of light to electricity through a simple solid state device.

(ii) Absence of moving parts.

(iii) Ability to function unattended for long periods as evidence in space programme.

(iv) Modular nature in which desired currents, voltages and power levels can be achieved by mere integration.

(v) Maintenance cost is low as they are easy to operate.

(vi) They do not create pollution.

(vii) They have a long effective life.

(viii) They are highly reliable.

(ix) They consume no fuel to operate as the sun's energy is free.

(x) They have rapid response in output to input radiation changes; no long-time constant is involved, as on thermal systems, before steady state is reached.

(xi) They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays. Solar cells can be used in combination with power conditioning circuitry to feed power into utility grid.

(xii) They are easy to fabricate, being one of the simplest of semi conductor devices.

(xiii) They have *high power to weight ratio,* this characteristic is more important for 'space applications than terrestrial, may be favorable for some terrestrial applications. The roof loading on a house top-covered with solar cells, for example, would be significantly lower than the comparable loading for conventional liquid solar water heaters.

(xiv) They can be used with or without sun tracking, making possible a wide range of application possibilities.

Their principal disadvantages are their *high cost,* and the fact that, in many applications, energy storage is required because of no insolation at night. Efforts are being made world-wide to reduce costs through various technological innovations.

26. Draw the current-voltage and power-voltage characteristics of a solar cell. What is fill-factor? Elaborate in detail the battery for solar applications. Compare working of DC to DC and DC to AC, converters. What is MPPT? What are the different MPPT algorithms? (Nov/Dec 2021)

Current-Voltage and power-voltage characteristics of a solar cell:

Fig.2.62 shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a single solar cell or panel is the product of its output current and voltage (I x V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

With the solar cell open-circuited, that is not connected to any load, the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells **open circuit voltage**, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells **short circuit current**, or Isc.

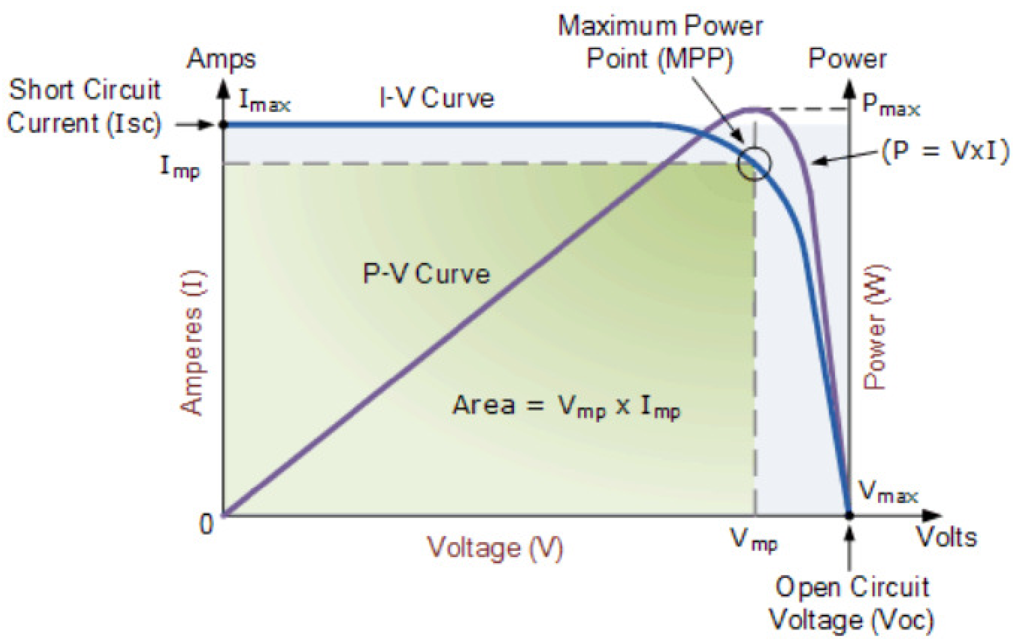


Fig 2.62 Current-Voltage and power-voltage characteristics of a solar cell

Then the span of the solar cell I-V characteristics curve ranges from the short circuit current (Isc) at zero output volts, to zero current at the full open circuit voltage (Voc). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between were the solar cell generates maximum power.

However, there is one particular combination of current and voltage for which the power reaches its maximum value, at Imp and Vmp. In other words, the point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the "maximum power point" or **MPP**. Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.

The maximum power point (MPP) of a solar cell is positioned near the bend in the I-V characteristics curve. The corresponding values of Vmp and Imp can be estimated from the open circuit voltage and the short circuit current: Vmp ≅ (0.8–0.90)Voc and Imp ≅ (0.85–0.95)Isc. Since solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature.

Thus far we have looked at **Solar Cell I-V Characteristic Curve** for a single solar cell or panel. But a photovoltaic array is made up of smaller PV panels interconnected together. Then the I-V curve of a PV array is just a scaled up version of the single solar cell I-V characteristic curve as shown.

FILL FACTOR:

FF = fill factor – The fill factor is the relationship between the maximum power that the array can actually provide under normal operating conditions and the product of the open-circuit voltage multiplied by the short-circuit current, (V_{OC} x I_{SC}) This fill factor value gives an idea of the quality of the array and the closer the fill factor is to 1 (unity), the more power the array can provide. Typical values are between 0.7 and 0.8.

Battery Storage.

The simplest means of storage on a smaller moderate scale is in electric *storage batteries,* especially as solar cells produce the direct electric current required for battery charging. The stored energy can then be delivered as electricity upon discharge. The common lead acid storage batteries, such as are used in automobiles, are not ideal for this purpose, but they are probably the best presently available. Extensive research in progress should lead to the development of more suitable batteries.

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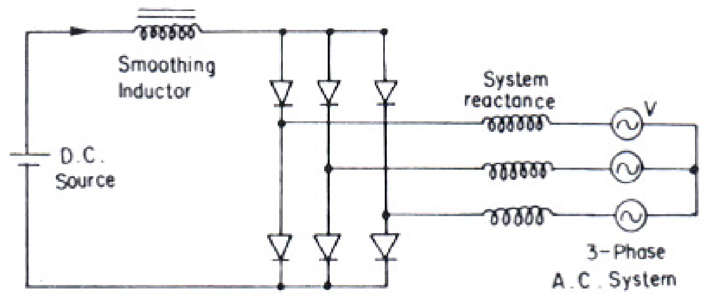

Fig 2.63 Current –fed line commutated inverters.

It is clear that the system photovoltaic offers the options of DC power, AC power, hydrogen and oxygen fuels in either gas or liquid forms from which electricity can be generated. The system has many advantages and disadvantages.

Maximum power point tracking (MPPT):

Maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) inverters to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and load.

The three most common MPPT algorithms are:

1. **Perturbation and observation (P&O):** This algorithm perturbs the operating voltage to ensure maximum power. While there are several advanced and more optimized variants of this algorithm, a basic P&O MPPT algorithm is shown in Fig 2.64.

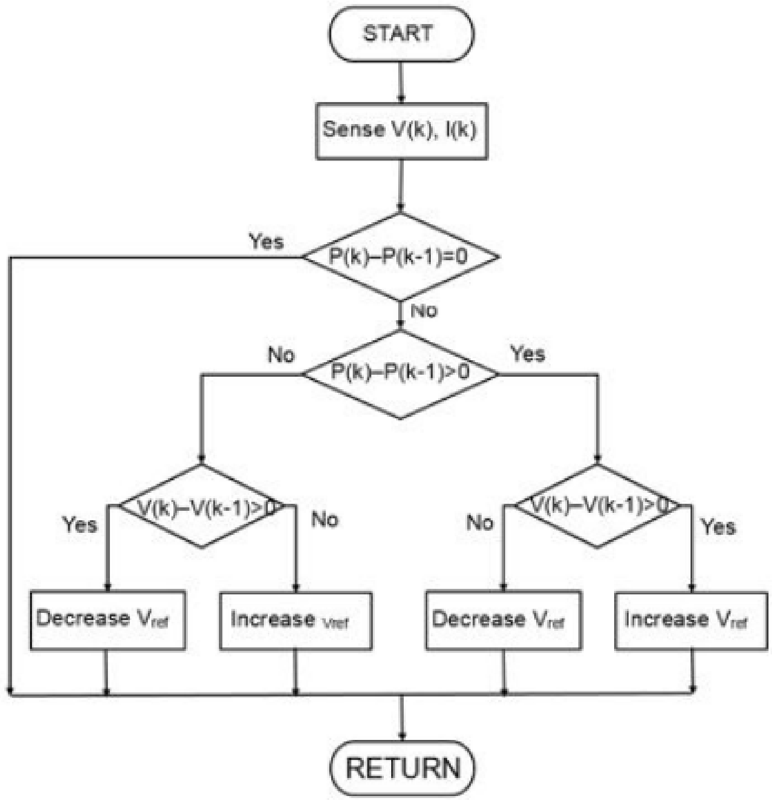

Fig 3.64 Basic P&O algorithm.

2. **Incremental conductance:** This algorithm, Fig 2.65 shown below, compares the incremental conductance to the instantaneous conductance in a PV system. Depending on the result, it increases or decreases the voltage until the maximum power point (MPP) is reached. Unlike with the P&O algorithm, the voltage remains constant once MPP is reached.

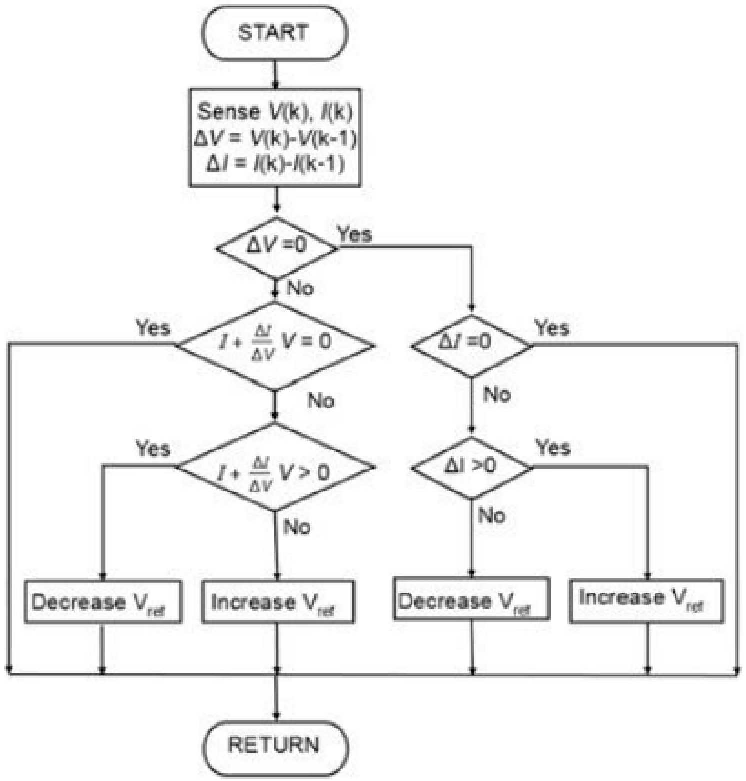

Fig 2.65 Incremental conductance algorithm.

3. **Fractional open-circuit voltage:** This algorithm is based on the principle that the maximum power point voltage is always a constant fraction of the open circuit voltage. The open circuit voltage of the cells in the photovoltaic array is measured and used as in input to the controller.